VOL. 249 AUGUST 1951 No. 8

American Journal of Science

Established in 1818 by Benjamin Silliman

EDITORS
CHESTER R. LONGWELL - JOHN RODGERS

ASSOCIATE EDITORS

REGINALD A. DALY
CAMBRIDGE, MASS.

A. F. BUDDINGTON
PRINCETON, N. J.

ADOLPH KNOPF
CARL O. DUNBAR
HENRY MARGENAU

RICHARD FLINT
HAROLD G. CASSIDY
G. EVELYN HUTCHINSON
NEW HAVEN, CONN.

LEASON H. ADAMS
WILMOT H. BRADLEY
WASHINGTON, D. C.

WILLIAM H. TWENHOFEL
ORLANDO, FLORIDA

HOWEL WILLIAMS
BERKELEY, CALIF.

FREDERICK J. ALCOCK
OTTAWA, CANADA

CECIL E. TILLEY
CAMBRIDGE, ENGLAND

GEORGE GAYLORD SIMPSON
NEW YORK, N. Y.

STERLING TOWER
NEW HAVEN, CONNECTICUT

Published monthly. Eight dollars a year. Seventy-five cents a copy.
Foreign, eight dollars sixty cents. Canada, eight dollars thirty-five cents.

AMERICAN JOURNAL OF SCIENCE

Established in 1818 by Benjamin Silliman

THE FIRST SCIENTIFIC JOURNAL IN THE UNITED STATES

DEVOTED TO THE GEOLOGICAL SCIENCES AND TO RELATED FIELDS

Editor: Chester Ray Longwell

Assistant Editor: John Rodgers

Executive Secretary: Elizabeth G. Weinman

Entered as second-class matter at the Post Office at New Haven, Conn., under the Act of March 3, 1879. Published monthly at Sterling Tower, Yale University, New Haven, Conn.

Subscription rate $8 per year (75 cents a number). Student rate $5 per year (application blanks available on request). Postage prepaid to the United States and Central and South America; 35 cents per year to Canada; 60 cents per year elsewhere.

The Journal completed its *first* series of 50 volumes in 1845, its *second* series of 50 volumes in 1870, its *third* series of 50 volumes in 1895, its *fourth* series of 50 volumes in 1920, its *fifth* series of 36 volumes in 1938. Since 1938 the numbering by series has been discontinued, and volumes are annual and bear the whole numbers as of 1818, that for 1939 being volume 237.

Back numbers and volumes, also cumulative indices of all series, may with few exceptions be obtained from the office of the American Journal of Science, Sterling Tower, New Haven, Conn. Positive microfilm copies of each complete volume may be purchased by subscribers to the paper edition from *University Microfilms*, 313 N. First St., Ann Arbor, Michigan. Regular subscribers may purchase each past year in microcard form, from *The Microcard Foundation*, Wesleyan University, Middletown, Connecticut.

INSTRUCTIONS TO CONTRIBUTORS

Manuscripts of articles submitted should follow the recommendations in the pamphlet "Suggestions to Authors" (Lane, 1935) and should be preceded by brief abstracts. They should be checked with special care before being submitted, to avoid changes in proof other than printer's errors.

References to literature should be listed alphabetically by authors at the end of the article. All references should be complete and should comprise in order: Author's name, year of publication. Full title: name of periodical or series, volume number, inclusive pages, place of publication (if needed to identify book or periodical). Except that the year should directly follow the author's name, references should follow the form given in "Suggestions to Authors" (Lane, 1935, pp. 16-29). As in this example, citations within the article should be to author and year, and to specific pages if appropriate.

Plates (photographs), *figures* (line drawings), and *footnotes* should each be numbered consecutively through each article, using arabic numerals. If two photographs form one plate, they are figures 1 and 2 of that plate.

Illustrations should be neat and legible and should include explanations of symbols used. Copy that cannot be reproduced cannot be accepted. Plates and figures should be capable of reduction to not more than 4 by 7 inches, all lettering being at least 1/16th inch high after reduction. When necessary, one large map or table can be accepted, if it will not exceed 7 inches in width after reduction. Line drawings should be in black India ink on white drawing board, tracing cloth, or coordinate paper printed in blue. Photographs should be positive glossy prints. Photostatic and typewritten material cannot be accepted as copy for illustrations.

Reprints. Thirty separate copies of each article will be furnished to the author free of cost and without previous notice from him; these will be without a cover. Additional copies will be furnished at cost, which will of course be greater if the article is accompanied by plates involving unusual expense. Copies will be furnished with a printed cover giving the title, author, volume, page, and year, when specially ordered.

Reference

Lane, B. H., 1935. Suggestions to authors of papers submitted for publication by the United States Geological Survey: U. S. Geol. Survey, Washington, D. C. (For sale by Superintendent of Documents, Washington, D. C., 25c.)

[American Journal of Science, Vol. 249, August, 1951, Pp. 553-568]

American Journal of Science

AUGUST 1951

A SEDIMENTARY STUDY OF DUST STORMS IN THE VICINITY OF LUBBOCK, TEXAS

G. FREDERICK WARN and WILLIAM H. COX

ABSTRACT. This study concerns the weather conditions and the sediment types and characteristics associated with dust storms during the spring months of 1950 in the vicinity of Lubbock, Texas. An analysis of ten storms revealed the following: 1. Severe storms of long duration resulted from deep low pressure areas which developed outside of the region and moved from west to east. 2. Dust was carried to a mixmum height of 25,000 feet. 3. An average of 1,756 calculated tons of sediment per storm was carried across a five mile front in the area of study. 4. An average of 121.8 calculated tons of sediment per storm hour was carried across this front. 5. Sediments were largely within 1/16-1/8 mm. grain sizes. 6. An average of two percent visible organic matter was found in the sediments. 7. Quartz comprised 55-90% of the sediments, clays 25-40%, carbonates 5-20%, gypsum about 5%, and magnetite, rutile and zircon less than one percent each. 8. Abrasional wear from wind erosion was most pronounced in quartz grains and in 1/8-1/4 mm. grain sizes.

INTRODUCTION

THIS paper reports a limited investigation of dust storms during the spring months of 1950 in the vicinity of Lubbock, Texas. The study includes: (1) weather conditions associated with the storms, (2) types and quantities of material carried by the wind, (3) the probable sources of wind-blown materials.

Raymond Sidwell (1938) made a somewhat similar study of the severe sand and dust storms in this area in the spring months of 1935 and 1936.

LOCATION AND SETTING OF AREA

Lubbock is on the South Plains just south of the Texas Panhandle and near the eastern margin of the High Plains of West Texas (fig. 1). The High Plains include an area of about 40,000 square miles, extending from the foothills of the Rockies on the west to an erosional escarpment on the east. Relief of the plains is remarkably slight; the nearly flat surface is broken locally by shallow circular or oval depressions, relatively deep and narrow stream valleys, and some

hummock or dune type land. The shallow depressions are the result of sub-surface solution and collapse and of surface deflation by winds. They are occupied by intermittent ponds and lakes.

Lubbock is surrounded by an extensive agricultural district. Soils in the area are largely unleached, are composed of reddish clay, silt and sand and are lime-accumulating. Soils containing caliche have a noticeably high lime content.

CLIMATE OF THE REGION

The regional climate is semi-arid with an annual precipitation of 9 to 35 inches. The mean annual precipitation over the past 39 years is 19.41 inches. Maximum precipitation occurs during May, June, July and August. The mean temperature range is from 34.5° F. in January to 80.0° F. in July. Average wind velocities are greatest in the months of February through May (Frost *et al.*, 1950).

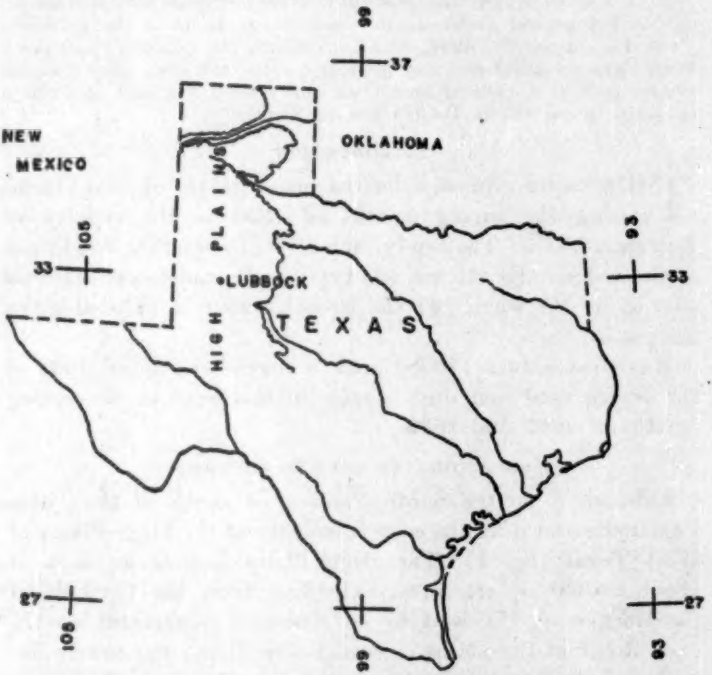


Fig. 1. Lubbock is situated south of the Texas Panhandle and west of the erosional escarpment of the High Plains.

GEOLOGY OF THE REGION

The rocks of the region are poorly consolidated clays, silts, sands and conglomerates deposited during the Pliocene epoch of the Tertiary period. Caliche, a lime-cemented clastic rock of uncertain origin, occurs at several levels in the Pliocene section and forms a durable cap rock at or near the surface over much of the area. Other than caliche, the sediments in the region are primarily water laid deposits, left by low-gradient, shifting streams flowing eastward and southeastward

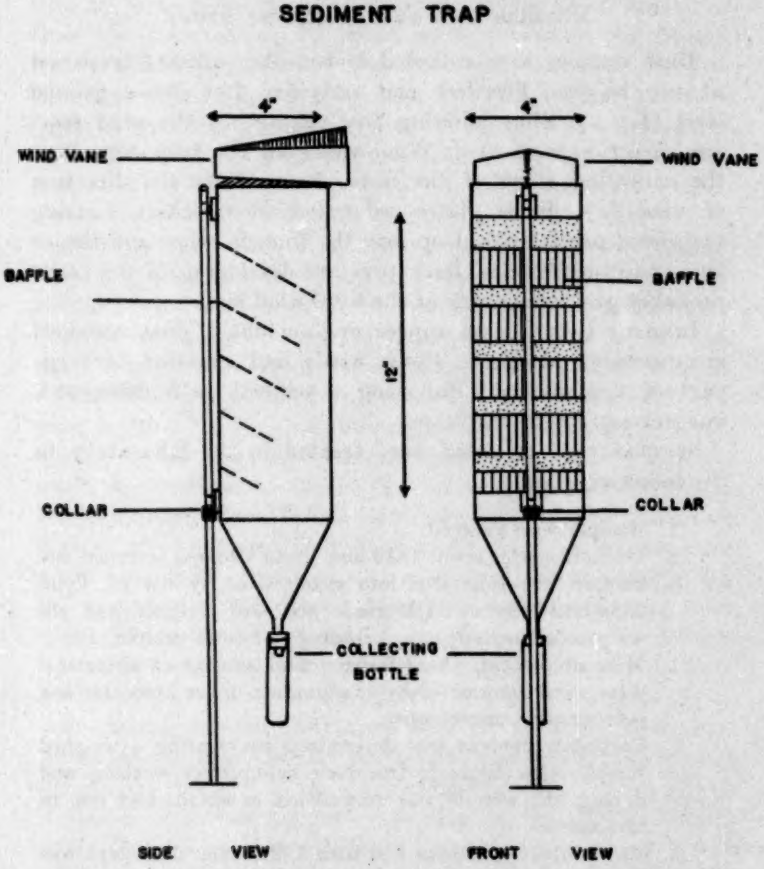


Fig. 2. Diagram of the type of trap used to collect windblown sediments in the Lubbock area.

from the Rocky Mountain Uplift of Colorado and New Mexico. These streams built broad piedmont alluvial fans and flood plains which were extended gradually eastward to approximately the eastern border of the Texas Panhandle. The result is an aggradational plain, sloping gently to the east-southeast and since tilted toward the Gulf of Mexico. In part the sediments have since been reworked and redeposited by wind. Some of the valleys and lake basins, carved in Pliocene and Cretaceous rocks, contain Pleistocene deposits.

METHODS AND PROCEDURES OF STUDY

Dust samples were collected in box-like sediment traps set at two heights, five feet and sixty-five feet above ground level (fig. 2). Sites allowing free passage of the wind from any direction were used. Wind vanes on the trap tops kept the collecting faces of the boxes turned into the direction of wind flow. Baffle plates reduced wind velocities, causing suspended particles to drop into the funnels below and thence into collecting bottles. Back pressure developing in the traps probably prevented entry of the total wind load.

In many instances an appreciable amount of dust remained in suspension after the storm winds had subsided. A large part of this material, following a vertical path downward, was not caught in the traps.

Samples thus collected were treated in the laboratory in the following manner:

1. Sample was weighed.
2. Organic matter about 1/16 mm. grain size was screened out.
3. Sample was separated into grade sizes by use of Tyler Standard Sieves. Each grade size was weighed and the weights converted into percentage of total sample.
4. Mineral content, characteristics and amount of abrasional wear were determined by examination under binocular and petrographic microscopes.
5. Carbonate content was determined by treating a weighed sample with dilute hydrochloric acid. After washing and drying, the sample was re-weighed to obtain loss due to carbonates.
6. Clay content (particles less than 1/256 mm. diameter) was determined by boiling a weighed sample in 500 ml. of water to which approximately three grams of sodium bicar-

bonate had been added. After deflocculation the clays were decanted. The remaining sample was washed, dried and re-weighed to obtain loss of clay size particles.

WEATHER CONDITIONS ASSOCIATED WITH DUST STORMS

Dust storms in the South Plains are of two types and originate in three kinds of weather conditions. One type is a local dust storm which develops because of weather conditions within the area. Such "dusters" are associated with afternoon and evening thunderstorm activity in the immediate vicinity, and are usually of slight intensity and short duration. Dust blows are caused by squall winds preceding the storms and by sudden downdrafts which develop as towering cumulus clouds at high levels begin to disperse. These storms are frequent in any of the months from February through August.

Another local type of storm is caused by the passing of frontal winds which develop when two unlike air masses meet within the area. These winds frequently pick up and transport topsoil and loose dust, but are usually followed closely by a drop in turbulence and/or by moisture conditions which eliminate dust storms of more than one-half hour duration. Frontal winds occur most frequently when cold air masses move into the area from the north in spring or fall months.

The second type of dust storm is more intense and originates from weather conditions outside of the study area. These storms move in from the southwest, west, northwest, north and northeast. Their place of origin may be Nevada, Utah, Arizona, New Mexico, Colorado, Montana, the Dakotas, Kansas or Oklahoma. They develop due to large low pressure areas frequently associated with a trough line extending along the east side of the Rocky Mountains. Winds blowing in a counterclockwise pattern into these low pressure cells develop velocities from 25 to 75 mph. The trough line is an elongate low pressure area which normally moves in an easterly direction causing a wind shift from west to north to northeast. Such trough lines usually extend through New Mexico and toward or into the Texas Panhandle (fig. 3).

Intense dust storms rarely develop to the east or southeast. This fact appears to have several explanations. Winds associated with low pressure areas to the east or southeast are deflected upwards at the escarpment marking the eastern

boundary of the plains. Hence, they tend to pass over the Lubbock area as upper air winds. Such winds tend to carry moisture landward from the Gulf and frequently result in moisture conditions which inhibit dust blowing. Further, the source area below the escarpment is largely covered by vegetation and thus limits wind loads.

Prolonged drought in the South Plains contributed to dust storm conditions. Precipitation in the Lubbock area was negligible from October 23, 1949, when 0.45 inches of rain

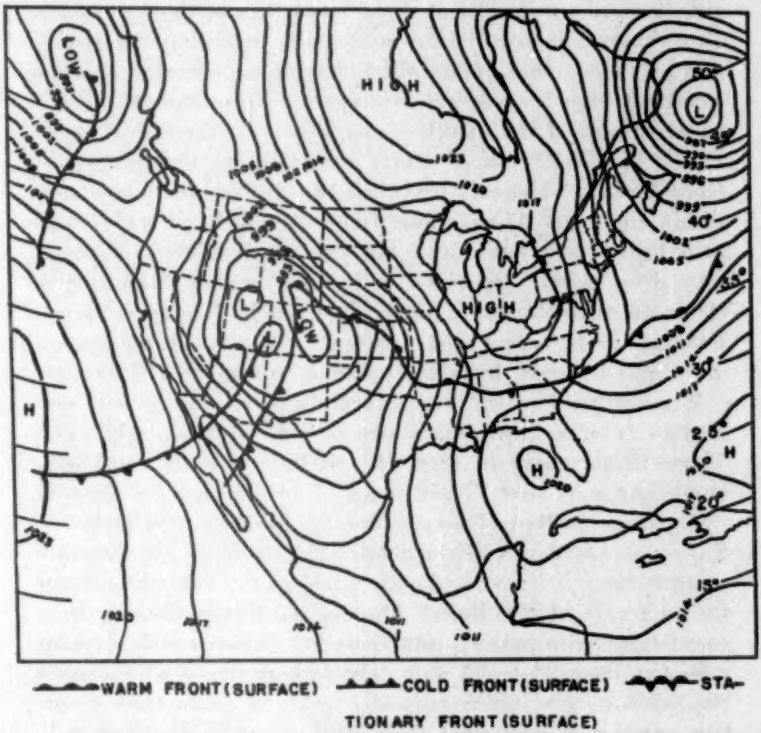


Fig. 3. Weather map showing the position of highs, lows and fronts on March 25, 1950, at the beginning of a severe dust storm which blew intermittently for three days. At 1:20 A.M., C.S.T., on the 26th, a record barometric low of 29.19 inches, reduced to sea level, was reached in the Lubbock area with maximum winds of 55 mph. A weak surface cold front followed the low pressure area as it moved eastward. The huge low was centered in Utah and Colorado with a shallow trough along the Central Rockies.

fell, to May 13, 1950, when 1.77 inches were recorded (Frost *et al.*, 1950).

TYPES, AMOUNTS AND CHARACTERISTICS OF THE SEDIMENTS

The wind-transported sediments studied consist primarily of organic matter, quartz, clay, carbonates, gypsum, magnetite, rutile and zircon. The sediments, excepting organic particles, fall mainly into three grain sizes: 1/8-1/4 mm.; 1/16-1/8 mm.; and less than 1/16 mm. The mode is in the 1/16-1/8 mm. grade size.

Visible organic matter consists of leaf and stem fragments from plants, bits of grass and humus. Such matter as could be sieved out constitutes, on an average, two percent by weight of the total wind load. Organic matter of less than 1/16 mm. grain size was not accounted for in the analyses.

Quartz, SiO_2, comprises 55 to 90% of the individual samples. It occurs as angular to sub-rounded grains, many of which bear a coating of iron oxide, an original cementing material, The grains of 1/8-1/4 mm. grade size are frequently pitted, frosted and polished. Approximately 20% of the grains are frosted and 15% polished while 30% show effects of pitting and scratching. Sub-rounded grains with an iron oxide coating are reworked sediments. They indicate a history of corrasional wear during transportation, then deposition, cementation and lithification. These sediments were subsequently reduced to rock waste which was transported by present day winds. Such transportation, if prolonged, would destroy the iron oxide coatings.

Carbonate materials comprise 5 to 20% of the sediments. These percentages vary considerably with the direction of the source area. Sediments from the south and southwest contain 18 to 20%; sediments from other directions contain from 5 to 10% carbonates.

Clay sized particles make up 25 to 40% of the sediments. Samples from the west and northwest carry an average of 29% clay, slightly higher than samples from the southwest. One sample from the south contained 10% more clay material than any of the other samples. The effects of type of source area and turbulence and velocity of the transporting winds on the percent of clay content in the wind load might be

determined by further sample collecting and correlation of weather data.

TABLE 1

Table of Calculations: Carbonate and Clay Content

Wind Direction	Weight of Sample	Weight after acid	% carbonate	Weight after deflocculation	% clay
N	.785	.710	9.55	.485	28.66
	.535	.480	10.28	.320	29.99
NW	2.395	2.175	9.18	1.460	29.85
	2.410	2.175	9.75	1.435	30.89
W	2.935	2.750	6.30	1.845	30.83
	1.945	1.820	6.42	1.235	30.06
SW	.245	.195	9.55	.135	24.49
	.325	.265	10.28	.320	29.99
S	.405	.335	17.28	.170	40.74

Gypsum, $CaSO_4 \cdot 2H_2O$, comprises about 5% of the sediments. It occurs as white to gray, crumbly, amorphous masses and as platy fragments. The major part of the gypsum probably was derived from alkali flats and playa lakes of the surrounding areas. Winds passing over the White Sands area of New Mexico might be expected to carry appreciable amounts of gypsum, although no materials from this area were available for a comparative study.

Magnetite, Fe_3O_4, comprises less than one percent of the sediments. It occurs as black, well-rounded grains and irregular fragments, and appears most frequently in the 1/16-1/8 mm. grade size.

Rutile, TiO_2, comprises less than one percent of the sediments. It occurs as dark red, sub-angular to rounded grains.

Zircon, $ZrSiO_4$, comprises less than one percent of the sediments. It appears as colorless and mauve, sub-angular to rounded grains. The above three minerals are all reworked from sediments and might be used to identify the source rocks from which they are wind derived.

Minor amounts of feldspar, garnet, and limonite also appear in the samples.

All particle sizes show some degree of abrasional wear but it is more pronounced in the 1/8-1/4 mm. grade size. These grains are probably subjected to more tractional travel than

are smaller ones, hence the greater amount of physical wear (Bagnold, 1941). Abrasional wear is well developed on magnetite and less well developed on quartz. Approximately 80% of the magnetite is rounded, 15% sub-rounded, and 5% sub-angular. About 5% of the quartz is rounded, 70% sub-rounded, 10% sub-angular, and 15% angular. About 20% of the rutile is rounded, 65% sub-rounded, and 15% sub-angular.

There is little variation in the amount of abrasional wear of magnetite, zircon, and rutile in the different samples. Quartz, however, shows an appreciable variation, both in direction of source area and in the height at which the sediments were trapped. Grains from the northwest and southwest are more rounded than those from the north, west, or northeast.

Sediments caught in the trap at the five foot level are more rounded than sediments collected in the upper trap. This additional rounding, doubtless, results from a greater amount of tractional travel undergone by sediments carried at or near ground level. These grains would be in nearly constant contact with the ground and with one another, rolling and impact producing relentless wear, while suspension borne particles would receive physical wear only by contact with one another (Bagnold, 1941).

QUANTITY OF MATERIAL CARRIED BY THE WIND

Particle sizes and quantities of material carried by the wind are determined by several factors such as air turbulence, wind velocity, air humidity, and the condition of the surface over which the air moves.

Turbulent or churning air movements are especially effective in dislodging surface particles and starting them in motion. The "devil duster," a dust-laden whirlwind common on the dry plains, is an excellent example of the effectiveness of vertical movement of air in picking up a load. In the Lubbock area winds generated by thunderstorms and swiftly moving weather fronts are commonly associated with high turbulence.

The competency of horizontal winds is in nearly direct ratio to the velocity (Udden, 1894). Loose clay and silt particles are shifted about close to the ground in the Lubbock

area by winds of 15 mph. Winds with velocities of less than 25 mph. seldom move an appreciable suspension load. Since wind speeds are lowest near the ground, horizontal winds are able to maintain greater loads when preceded or accompanied by high turbulence.

Ground with noticeable moisture content at the surface does not offer a load to the wind unless the wind is continuous and is accompanied by low relative humidity. In this case, soil moisture is quickly lost and any fine material at the surface is subject to deflation by winds of 25 mph. velocity or greater. Wind blowing across a vegetation covered surface finds a negligible load. In fact, such a wind encountering the resistance of the ground cover is sufficiently slowed down to force a partial loss of any traction load that it might hold (Chepil, 1946a, b). Pastured lands, stubble fields, and strip crops are especially effective in reducing wind speeds and wind loads (Nielsen *et al.*, 1949). Freshly cultivated fields, on the other hand, are generally open to wind erosion. Fields that are furrowed perpendicular to wind flow tend to slacken the velocity and cause a loss of heavier particles to the wind. Furrows aligned parallel to wind flow act as channels which cause an increase in velocity of the wind directed through them. Erosion is thus increased by these wind channels. Freshly cultivated fields develop a thin covering of loose clay and silt following a pelting by raindrops or hail. If left uncovered they supply a ready load of fine sediments to both horizontal and vertical air movements, once the soil has been robbed of its moisture. The dust storm of March 18 was especially effective because of a record low of six percent relative humidity. Moist winds, unable to dry the ground surface, seldom obtain a noticeable load. However, sudden updrafts in moist currents beneath cumulonimbus clouds were observed to sweep large amounts of dust upward where they remained suspended unless washed out by precipitation. The overall conditions most conducive to dust storms are: dry, barren, finely broken soil open to winds of high turbulence followed by high sustained velocity and accompanied by conditions of low relative humidity (Free, 1917).

In this study an experimental attempt was made to determine the quantity of sediments, by weight, which passed over Lubbock during a given dust storm. The mathematical

calculation of the quantity of sediments is based on the ratio of the area of the face of the sediment trap to the area of a hypothetical vertical screen set across Lubbock at right angles to the wind. The weight of sediment caught in the trap is proportional, then, to the weight of sediment that would be stopped by a vertical screen five miles wide, which is the approximate width of Lubbock.

This gives the formula: $\frac{wh}{d} :: \frac{WH}{D}$

in which w is the width of trap, h is height of trap, d is weight of sediments caught in the trap, W the width of the hypothetical screen, H the average height of the dust during the storm, and D the quantity of material that would be stopped by the screen.

The dust storm calculations involved the following data:

w — 4″

h — 12″

W — 5 miles

d and H variable with different storms.

Calculations for one of the most severe storms of the study follows:

w 4″ d 7.32 grams
h 12″ H 18,000 ft.
W 5 mi.

$$\frac{4'' \times 12''}{7.32 \text{ gms.}} :: \frac{5 \times 5280' \times 18{,}000' \times 144''}{D \times 2{,}000 \text{ lbs.} \times 454 \text{ gms.}}$$

$$D = \frac{5 \text{ mi.} \times 5280 \text{ ft./mi.} \times 18{,}000 \text{ ft.} \times 144 \text{ sq. in./sq. ft.}}{48 \text{ sq. in.} \times 2{,}000 \text{ lb./ton} \times 454 \text{ gm./lb.} \times 7.32 \text{ gm.}}$$

D = 11,492.7 tons. This figure is for a period of 14.5 hours.

D = 792.6 tons/hr.

Table 2 shows the quantity of material which passed over Lubbock during ten of the dust storms which were noted in this study.

TABLE 2

Storm Date	Wind Direction	Sustained Velocity	Maximum Velocity	Total Hours of Storm Wind (approx.)	H Average	d grams	D(tons)	D(tons/hr.)
3-15	WSW	25	50	5.5	7500′	.870	569.14	103.48
3-18	WNW	40	60	11.0	9000′	2.650	208.03	18.91
3-25, 26	SW-S	30	55	20.0	14000′	3.415	4,193.15	209.16
3-27	WNW	35	45	20.0	8000′	.895	624.52	31.23
3-28	NNW	20	35	6.5	3500′	.175	53.42	8.22
3-30	S	25	40	6.0	3000′	.135	3.93	.66
4-3	W	30	40	6.5	4000′	.615	209.86	32.29
4-3, 4	NNE	35	65	13.5	5500′	1.005	139.69	10.35
4-18	WNW	25	35	6.5	3500′	.235	71.78	11.04
5-4	SW-W	58	75	14.5	18000′	7.320	11,492.70	792.60
						Total	17,566.22	
							Average tons/storm: 1,756.62	Average tons/hour: 121.8

In the above results it was assumed that the distribution of particles per unit of air was constant at all levels, since data were not available for plotting a distribution curve. Probably the distribution was considerably less above the 65 foot trap level but considerably greater below this level. The trap at the 5 foot level was not used in the quantitative study because of leakage during several storms. In the 65 foot trap an unknown amount of sediment failed to enter due to back pressure, hence the results of the quantitative survey are probably conservative. Too, maximum dust heights were frequently maintained from 1/2-3/4 of the duration of the storms. Therefore, by using the average height of the dust in a given storm, results again should be on the conservative side.

COMPARISON OF SAMPLES

A comparison of the sediment samples indicates that those collected from the southwest and northwest are similar in texture, composition and abrasional wear. These samples differ from those collected from the west and northeast in that they show more abrasional wear, are coarser, contain less organic matter and tend to be lighter in color. However, sediments from the west are finer, show less abrasional wear, contain more organic matter and are darker in color than sediments from the northeast.

The mode of all samples is in the 1/16-1/8 mm. grain size. However, samples from the southwest and northwest contain a greater percentage of this grain size than samples from the west and northeast. Average sustained wind velocities of 35 mph. obtained in the former sample sets and of 30 mph. in the latter. In no case did winds of greater than average speeds carry an unusual percentage of sediments in the 1/8-1/4 mm. grain size.

Sediments collected in the traps were compared with surface samples collected in the area surrounding Lubbock. In two instances only did samples have comparable characteristics. Sediments collected during storms with wind velocities of 20 to 25 mph. were similar in most respects to samples collected at the surface from the immediate vicinity of Lubbock. When winds exceeded 25 mph. a larger percentage of sediments dissimilar to local materials occurred in the trap sam-

ples, and this percentage increased proportionally to the velocity of the winds. This would indicate that winds below 25 mph. derive the major part of their loads from local sources. The other instance in which surface samples and trap samples were comparable was in the 1/16-1/8 mm. grain size. Trap sediments from the southwest were comparable to surface sediments collected at Denver City, 80 miles southwest of Lubbock.

Surface sediments were also collected at 20 mile intervals between Lubbock and Clovis, New Mexico, 105 miles to the northwest. A comparison of these samples with the trap sediments blown from the northwest failed to reveal any noticeably like characteristics. This is taken as an indication that most of the northwest winds derive the greater part of their loads beyond the 105 mile radius.

CONCLUSION

Severe dust storms in the Lubbock area are due to deep low pressure cells which develop outside of the state, usually to the northwest or north. These storms transport surface materials into and beyond the Lubbock area while less severe storms are usually of local origin and transport local surface materials. The relative amounts of material added to or removed from the surface in this area were not measured.

Wind blown sediments consist primarily of quartz grains (55-90%) in sizes of 1/16-1/8 mm. Clay-sized particles (less than 1/256 mm. diameter) comprise 25 to 40% of the sediments. Carbonate materials make up 5-20% of the sediments. About 5% of the sediments are made up of gypsum, and an average of 2% are of visible organic matter. Magnetite, rutile and zircon contribute less than 1% each to the sediments.

Abrasional wear in the sediments is largely primary; that is, the abrasion took place prior to deposition and lithification of the original sediments. Wind transportation of rock waste and soils derived from these primary deposits has accomplished further physical destruction of the particles. The heavier particles, 1/8-1/4 mm. grain sizes, are subect to more tractional transportation than smaller grain sizes, hence show a greater amount of physical wear. Quartz grains transported

from the northwest and southwest are more rounded than those originating from the west or north. The grain characteristics of wind transported materials—rounding, frosting, scratching, pitting, and size sorting—are most pronounced in quartz grains.

The quantity of material carried in a given dust storm depends on weather factors and on the condition of the ground over which the winds travel. Maximum wind loads are obtained under weather conditions of low humidity, high turbulence and sustained wind velocities of more than 25 mph. Surface conditions conducive to dust storms include: dry, barren, cultivated soil furrowed parallel to wind flow. The latter might be overcome by cover crops planted with the last precipitation of late summer or early fall months; by irrigation preceding spring dust storm conditions; by proper cultivation of fields (Nielsen *et al.*, 1949); by preservation of natural vegetation covers through proper grazing techniques; and possibly by precipitation artificially induced.

In ten of the dust storms in the Lubbock area a calculated total of 17,566.2 tons of sediment crossed the 5 mile width of the city. An average of 121.8 tons per hour was carried across the city during these storms. Surface sediments were carried to a maximum reported height of 25,000 feet.

Future studies, with more complete sampling, might reveal: 1. Size, shape, and mineral sorting at various heights. 2. Effects of corrasional wear on sediments carried at various levels above ground. 3. The vertical distribution of particle sizes during storms of different wind velocities. 4. A more accurate calculation of the amount of material carried in traction and suspension per storm hour.

References

Bagnold, R. A., 1941. The physics of blown sand and desert dunes, Part I, Wm. Morrow & Company, New York.

Chepil, W. S., 1946a. Dynamics of wind erosion: IV. The translocation and abrasive action of the wind: Soil Science, vol. 61, pp. 167-177.

———, 1946b. Dynamics of wind erosion: VI. Sorting of soil materials by the wind: Soil Science, vol. 61, pp. 331-340.

Free, E. E., 1917. The movement of soil material by the winds: U.S. Dept. Agr., Bur. Soils, Bull. 68.

Frost, Harold L., and others, 1950. Local climatological summary, 1949, Lubbock, Texas: U.S. Dept. Commerce, Weather Bur. Dept., Ft. Worth, Texas.

Nielsen, James L., and others, 1949. Physical land conditions in Kit Karson County, Colorado: Soil Conser. Service, Physical Land Survey no. 43.

Sidwell, Raymond, 1938. Sand and dust storms in vicinity of Lubbock, Texas: Econ. Geography, vol. 14, pp. 96, 99-102.

Udden, J. A., 1894. Erosion, transportation and sedimentation performed by the atmosphere: Jour. Geology, vol. 2, pp. 318-331.

Texas Technological College
Lubbock, Texas
Baroid Well Logging Company

[American Journal of Science, Vol. 249, August, 1951, Pp. 569-590]

ABRASION OF NINE MINERALS OF SAND SIZE IN BALL MILLS

HAROLD L. ALLING

ABSTRACT. The abrasion of mineral grains, whether in nature or in controlled laboratory experiments, such as in ball mills, is a complex process. Much is still unknown. The attempt was made to investigate the mechanical abrasion of nine minerals of sand size treated separately, without water, not necessarily to imitate nature. The results show that ball mill abrasion reduces size, increases circularity and roundness; that each mineral has its own peculiarities. The multiplicity of the methods of grain size analysis necessitates better codification and the establishment of conversional factors.

INTRODUCTION

IF experimentation is combined with observations in the field and in the laboratory, the history of rocks can be interpreted. Both sight and insight are required.

This paper is based upon laboratory measurements of nine minerals, crushed and screened to sand size, during abrasion in ball mills. These methods, however, do not imitate nature. The number of variables involved in the process is so large that it is necessary to hold one factor constant while another is changed. This is arbitrary, of course, but it means that quantitative values eventually can be assigned to each of these factors, leading to a better understanding of nature's products. While much progress has been made in the study of abrasion, the work is far from finished; hence the results so far obtained are not necessarily directly applicable to observations in the field. A gap still exists between the results of the experimental laboratory and field observations.

The conditions of the experimental work were as follows: (1) the initial size of the mineral grains was limited to that of sand as defined by the author (1943, pp. 266, 269), and confined to 0.1 to 1.0 mm. in range; (2) the products of abrasion were allowed to accumulate; (3) the ball mills were operated without water for a total of 1000 minutes, at 150 rpm, an equivalent of 28 kilometers of travel distance; and (4) the minerals were ground separately, not in several groups as Thiel (1940) did.

Krumbein (1941b) has experimented with pieces of limestone of pebble size which were abraded in the presence of

water; the measurements were made after the pieces had been washed free from the powder due to abrasion. The results from these various experiments are not the same; the factors were different. In nature "sorting and abrasion are concomitant; and experimental work is likely . . . to be extrapolated beyond reasonable limits." (Pettijohn, 1949, p. 391).

EQUIPMENT AND PROCEDURE

The ball mills consisted of round glass bottles, 5.8 cm. in outside diameter, 6.4 cm. in height, fitted with metal screw tops. Each was supplied with three ordinary glass marbles, each of about 5 grams in weight. The jars were rotated horizontally (Alling, 1944, p. 104).

TABLE 1

Minerals Used

Mineral	Approximate Composition	Locality
Calcite	$CaCO_3$	Antwerp, New York
Andalusite	Al_2SiO_5	Pennington County, South Dakota
Quartz	SiO_2	Pink, Port Henry, New York
Garnet	$Gros_{15}$ Pyr_{45} Alm_{40} $Speg_5$*	Gore Mountain, Warren Co., N. Y.
Zircon	$ZrSiO_4$	Cardiff Township, Ontario, Canada
Tourmaline	$H_2Na(Fe,Mg)Al_3B_3Si_4O_{21}$	Pale Green, San Diego County, California
Microcline	Mic_{85} Ab_{10} An_5	Spruce Pine, North Carolina
Sillimanite	Al_2SiO_5	Near Custer, South Dakota
Hornblende	$NaCa_2(Mg,Fe)_4Al_2Si_8O_{22}(OH)_2$	Renfrew County, Ontario, Canada

* Levin, 1950, p. 836.

The minerals listed in table 1 were crushed by a hammer on a steel block, magnetically cleaned, thoroughly screened, —40 + 60 mesh, which approximates sand size. Twelve grams were introduced into each mill. A microsplit was devised by

TABLE 2

Number of Grains Measured

Mineral	Characteristic	Grains	Total
Calcite	Size	1385	
	Circularity	641	
	Roundness	728	2754
Andalusite	Size	1434	
	Circularity	943	
	Roundness	822	2199
Quartz	Size	1406	
	Circularity	435	
	Roundness	610	2451
Garnet	Size	1173	
	Circularity	418	
	Roundness	647	2238
Zircon	Size	1373	
	Circularity	1495	
	Roundness	1296	4164
Tourmaline	Size	1503	
	Circularity	467	
	Roundness	735	2705
Microcline	Size	1260	
	Circularity	505	
	Roundness	502	2267
Sillimanite	Size	1339	
	Circularity	1322	
	Roundness	1229	3890
Hornblende	Size	1239	
	Circularity	1811	
	Roundness	1347	4397
			27065

rotating on a vertical axis the bottom pan of the set of screens. By slowly pouring the entire contents of each mill, separately, after removing the marbles, into the center of the pan, the

mineral grains were driven by centrifugal force to the rim. A complete segment of this ring of material was removed by a narrow spatula and mounted on a microscopic slide under a cover glass in immersion oil. The rest was restored to the mill for further abrasion. Samples were taken at specific times.

Three separate sets of microscopic measurements were made; (1) determination of the projection size, for frequency-distribution curves, using the diaphragm method (Alling, 1941), (2) circularity (Rittenhouse, 1943), (two dimensional sphericity) according to size, and (3) roundness (Krumbein, 1941a) also according to size.

RIGOR OF ABRASION

One of the factors affecting the results is the rigor of abrasion. This can be varied by changing the rotational speed of the ball mills, changing the number of balls, using marbles of different weight, and so on. In table 3 some suggestions are offered regarding the rigor of abrasion.

TABLE 3

Rigor of Abrasion

Character	Terms	Scale*
Pounding	Very vigorous	.9
		.8
	Moderately vigorous	.7
Grinding	Very strong	.6
		.5
	Moderately strong	.4
Polishing	Moderately gentle	.3
		.2
	Very gentle	.1

* Proposed symbols, of approximate quantitative values only.

Those who have made thin sections and polished blocks of ores for microscopic examination appreciate the difference between grinding and polishing. The preparation of the nine minerals on the anvil is obviously "pounding" (.7 - .9); that in the ball mills is "grinding." The minerals themselves produce their own abrasive.

Gentler processes have been investigated, as in the case of

calcite and serpentine in gentle currents of water. These minerals can be exceedingly well rounded (Fay, 1948) after a long time.

The variation of the rigor of the process not only varies the rate of size reduction in a given time but in some cases causes a difference in the order in which individual minerals are reduced. In the matter of roundness and circularity this is clearly the case. It does not follow that if the rigor is reduced by one half, the same result will be obtained in twice the time. Consequently the distance of transportation is not an independent variable. In nature, the sorting and separation of the fine and the coarse grains, the round from the angular grains, is contemporaneous with abrasion. Nature does not maintain a constant degree of rigor.

INITIAL SHAPES

Many investigations, including those of Thiel (1940) and Alling (1950), have shown that fragments of different minerals, produced on an anvil by a hammer, are of different shapes. When the fragments are screened these differences are reflected in the frequency-distribution curves pertaining to size, whether in the form of modes or medians. This element of shape also appears in microscopic measurements of loose grains lying on a glass slide; the preferred orientation of the grains, controlled by the shape, is ever present.

The size of mineral grains can be measured in the following ways: (1) three dimensionally, in terms of the three axes, all at 90° from each other, (2) as random sections in thin sections, which are two dimensional, and (3) as projection areas of loose grains. The first method is applicable to pebbles and boulders but is difficult or impossible to apply to sand and silt-sized particles. The second method, the use of thin sections, has not been used as much as it perhaps should. This may well be the preferred method, for the results would be commensurable with data obtained from thin sections of sedimentary rocks, one of the ultimate goals of such experimental work. Nevertheless, the author chose the third method, that of projection, as more convenient and less expensive. The three methods produce different results.

The shape was measured as circularity, approaching two dimensional sphericity. This was determined by comparing the

microscopic images with diagrams based upon and extended from those of Rittenhouse (1943). In a like manner, roundness was ascertained from drawings patterned after those of Krumbein (1941a). The scale of roundness used was 0.1 (least round) to 0.9 (most round) rather than from zero to 1.0 as is perhaps customary (Pettijohn, 1949, p. 51). Conversion to the other scale can be done by using table 4.

TABLE 4

Conversion Table for Roundness

Scale Used 0.1 - 0.9	Conventional Scale 0 - 1.0
.1	0
.2	.12
.3	.25
.4	.37
.5	.50
.6	.62
.7	.75
.8	.87
.9	1.00

It is well to note that freshly broken fragments rarely possess zero roundness as Pettijohn pointed out (1949, p. 57); certainly the average of all of the minerals here investigated is above 0.1 on the scale used, therefore the low roundness end of the scale is perhaps theoretical. This is not a valid criticism of such scales, however.

RELATION OF ROUNDNESS AND CIRCULARITY TO SIZE

It is well recognized that roundness and circularity values depend upon size (see Thiel, 1940). This relationship has been diagrammed by the author (Alling, 1950, p. 143), consequently in reporting the roundness of mineral grains the corresponding grain size should be given as well. As both roundness and circularity usually rise with increase in size, they are theoretically related to each other, but the exact relationships are not necessarily linear. The present status of the problem seems best expressed by scatter diagrams. But each mineral here investigated evidently has its own peculiarities in this respect, which can be demonstrated if the minerals are treated separately.

PRESENTATION OF DATA

The following explanation is necessary for the interpretation of the curves here presented. The initial values, that is

at zero minutes of rotation, are those based upon measurements of *screened* grains. Thorough shaking of the sieves, —40 +60 mesh, removed the smaller sizes, less than 0.30 mm. in diameter. In the ball mills, small fragments are at once produced. As smaller grains are less round and less circular, the average value of the whole is thereby reduced, and this is the cause of the sag in the curves early in the stages of rotation, from 25 to 300 minutes. Each mineral differs somewhat in this respect (figs. 1 and 2).

The data, upon which this paper is based, are sufficiently extensive to permit the construction of a large number of two dimensional curves, many of which were drawn. The values of roundness and circularity were calculated from the frequency-distribution curves of these properties in percentage of number of grains for each size class interval. This can result in 12 two dimensional diagrams for each of the time-class interval ranges, for each of the nine minerals, or a

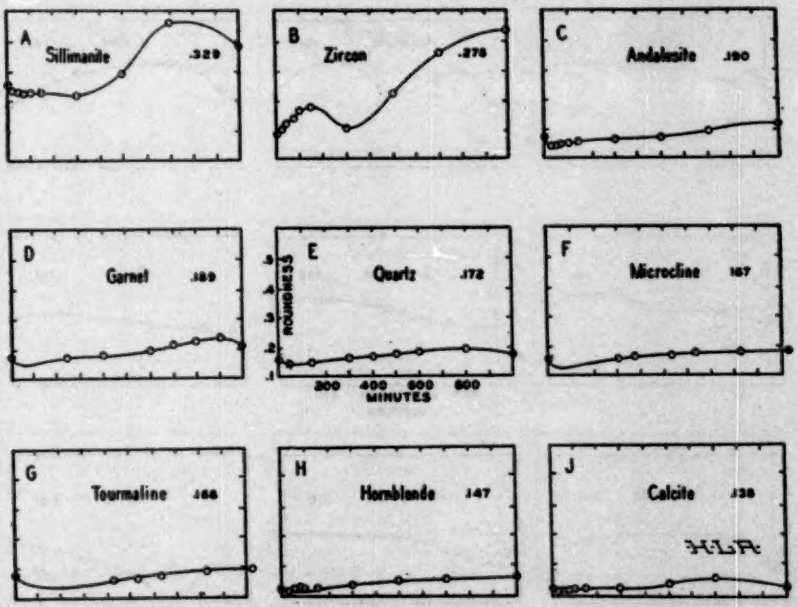


Fig. 1. Roundness of the nine minerals, arranged in order of most round to least. The numbers are averages for the entire thousand minutes in rotating ball mills. See table 4 for scale.

total of 1800. To reduce the number of diagrams, not only for the sake of the reader but for that of the printer and author as well, averages were used. While the advantages apparently outweigh the disadvantages, considerable detail and possibly some significant information is so obscured that it is largely lost.

The following averaging was performed; the value of the roundness and the circularity for each size class interval were averaged without weighting. These averages were plotted against minutes of rotation. To compare the characteristics of each mineral, the averages for each length of time of rotation were averaged for the complete thousand minutes.

Each mineral gave inherently different results, but direct comparisons are none too satisfactory, because each has its own individual initial shape and as a consequence possesses a different screen size. The difference between the initial value and the average provides a figure that renders them comparable.

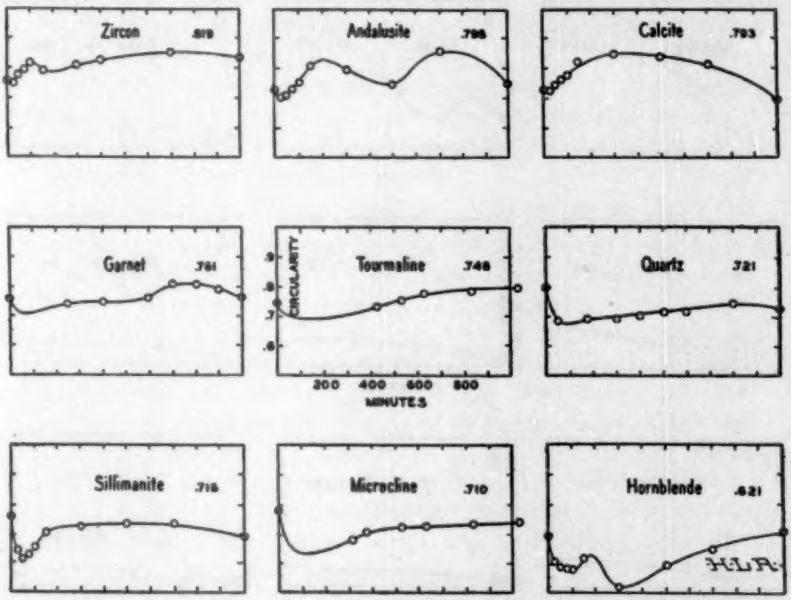


Fig. 2. Circularity of the nine minerals, arranged in order of most circular to least. The numbers are averages for the entire thousand minutes in rotating ball mills.

COMPARISON OF THE ABRASIONAL CHARACTERISTICS OF THE NINE MINERALS

The results obtained by the present writer are compared with those previously presented by other investigators. In table 5 the order of various minerals to resistance to abrasion are given. As some investigators have reported upon more minerals than the author studied, it was necessary to select those minerals from such lists that were included in the group here abraded. Even though thus selected, the original order of these investigators has been maintained.

Comparison of the eight columns of table 5 shows a lack of complete agreement. Some of the irregularities may be important, others may not be. Some may be due to errors. Still it can be argued that the total number of the variables is unknown; only a few have been taken into account, such as the presence or absence of water.

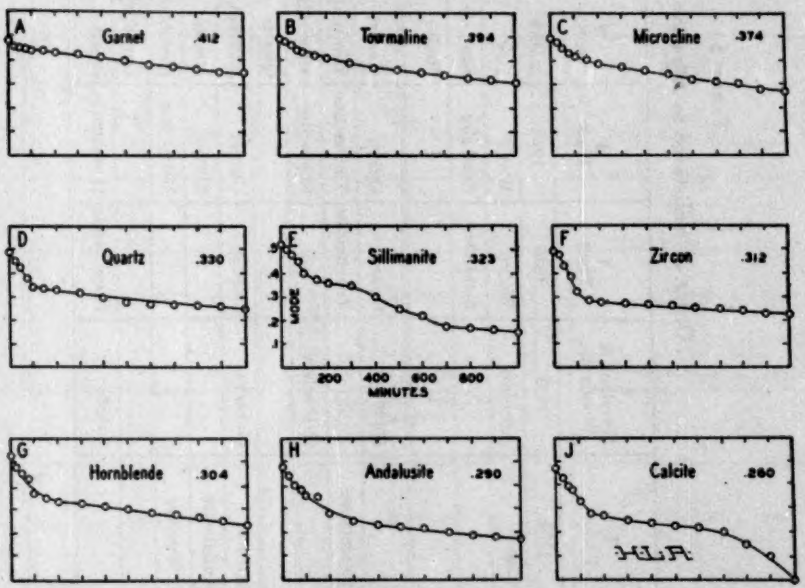


Fig. 8. Mode size of the nine minerals, arranged in order of most resistant to abrasion to least. The numbers are averages for the entire thousand minutes in rotating ball mills.

TABLE 5

Order of Resistance to Abrasion; Most to Least

	1 Freise	2 Marsland & Woodruff	3 Theil	4 Theil	5 Alling	6 Alling	7 Alling	8 Alling
	1931	1937	1940	1945	1950	1950	1950	1950
	Water	Air blast	Water	Water	Dry	Dry	Dry	Dry
			Sand size	Sand size	Sand size	Sand size	Sand size	Sand size
					Modes	Medians	Mode differences	Median differences
1		Quartz	Quartz	Quartz	Garnet	Microcline	Garnet	Tourmaline
2	Tourmaline		Tourmaline	Tourmaline	Tourmaline	Tourmaline	Tourmaline	Microcline
3		Orthoclase		Microcline	Microcline	Garnet	Microcline	Garnet
4					Quartz	Hornblende	Quartz	Andalusite
5	Garnet	Garnet	Garnet	Garnet	Sillimanite	Sillimanite	Zircon	Calcite
6	Andalusite			Zircon	Zircon	Zircon	Andalusite	Quartz
7	Orthoclase			Microcline	Hornblende	Quartz	Sillimanite	Zircon
8					Andalusite	Andalusite	Calcite	Hornblende
9		Calcite	Hornblende	Hornblende	Calcite	Calcite	Hornblende	Sillimanite

Another view is that the order is not as significant as the relative place in the table. Hence there is a general agreement that the least resistant minerals are hornblende, calcite, and sillimanite. Intermediate substances are andalusite and zircon, while the most resistant are microcline, garnet, quartz, and tourmaline.

Still there are discrepancies. Of these that of quartz is striking. In the author's lists this mineral occupies positions 4, 7, 4, and 6, in a total of 9 minerals, while it is first in the columns of other investigators. It is well known (Alling, 1950, pp. 143-144) that quartz characteristically breaks into long splinters. Under the action of the rolling marbles long thin grains would be broken into smaller pieces of less roundness. It would seem that this characteristic is a factor dependent upon the kind as well as the rigor of the abrasive processes.

Pettijohn (1949, p. 516) has summarized the factors that are involved in the resistance to abrasion.

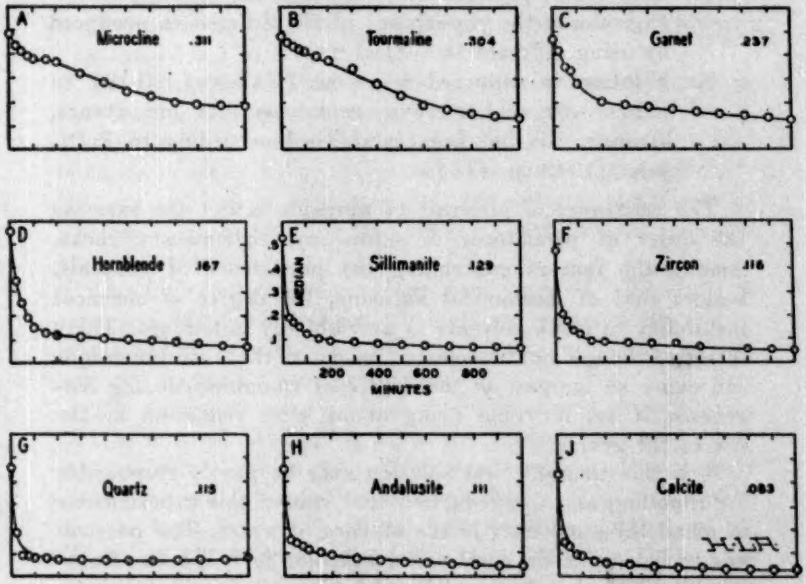


Fig. 4. Median size of the nine minerals, arranged in order of most resistant to abrasion to least. The numbers are averages for the entire thousand minutes in rotating ball mills.

1. Thiel's order approximates the order of hardness (which the present author would not stress).
2. Cleavage plays a role. (This is important).
3. The tenacity of the mineral. (This is involved in cleavage).
4. The above are related, at least theoretically, to the kind of ionic packing in the crystal lattice. Fairbairn's (1943) packing index, however, is closer to the order of disintegration due to weathering than to mechanical wear.
5. Variations in the rigor of abrasion may vary the results of such experimental work. (This is very evident).
6. The present author calls attention to the fact that the order of resistance of minerals to abrasion also depends upon the statistical measure used. Usually such lists are based upon the reduction in size in diameters. If, however, the *median* size is substituted for the *mode* size, the order may not be maintained. Lacking the data of the previous investigators, the writer is unable to evaluate the importance of the differences produced by using different statistical units.
7. Solution is supposed by some (Galloway, 1919) to reduce size and increase roundness; its importance, however, has not been established according to Pettijohn (1949, p. 418).

The resistance of minerals to abrasion is not the same as the order of persistence in subsequent sedimentary rocks. Among the factors controlling the persistence of minerals, besides that of mechanical abrasion, the degree of chemical instability in earth solvents is undoubtedly important. There is some, though not conclusive, evidence that solution alone can cause an increase in the degree of roundness during diagenesis. If so, it would bring about some reduction in the size of the grains.

It is this thought that solution may be partly responsible for rounding and size reduction that caused this experimenter to grind these minerals in the absence of water. The purpose was to determine the mechanical behavior in ball mills. Rotating them dry has been criticized because it does not imitate nature. It is necessary, however, to hold one variable constant while investigating another.

RESULTS IN ROUNDNESS

"Roundness has to do with the sharpness of the edges and corners" (Pettijohn, 1949, p. 49). This was stressed by Wadell (1935) and is accepted here. The concept is independent of shape.

There is a definite correlation between roundness and size (Wentworth, 1932, p. 222; Pettijohn and Lundahl, 1943). The materials reported upon were "sands," without specifying the mineral composition. "Sands" in a plot of roundness versus size result in scatter diagrams showing a general trend. It has been shown elsewhere (Alling, 1950, p. 141) that well-defined curves result if the minerals are treated separately.

The comparison of the roundness of the nine minerals during abrasion is complicated by the fact that the initial size of each is different. Since size and roundness are functions of each other, this would affect the degree of roundness as well. Through the practice of averaging, the differences between the initial and average values provides a figure that makes comparisons possible. These are shown in figures 5A and column 1 in table 7.

The tabulation of the roundness of the nine minerals reveals that zircon is the most rounded and tourmaline the least. This is perhaps a surprise in that the roundness of these two minerals in many sedimentary rocks is usually high and much the same. It can be suggested that the differences are due to differences in the vigor of the abrasion. There is need for more experimentation.

The high initial and average roundness of sillimanite is notable. This shows that not all roundness is necessarily due to abrasion. Some roundness of this mineral may well be but slightly modified from the original.

The values of roundness of quartz obscures a peculiarity of the mineral. Averaging hides the observations that there are individual grains with high roundness even though they have not been subjected to abrasion. Some initial values may run as high as .8 (.87 on the Pettijohn scale, 1949, p. 51. See table 4). It was suggested (Alling, 1950, p. 141) that this was due to the conchoidal fracture, so characteristic of this mineral. By the same token, quartz often occurred as thin splinters particularly at the start. Well rounded grains

TABLE 6

Initial and Average Values. In order of Averages.

Roundness				Circularity				Mode				Median			
No.	Mineral	Initial	Ave.	No.	Mineral	Initial	Ave.	No.	Mineral	Initial	Ave.	No.	Mineral	Initial	Ave.
1	Sillimanite	.258	.329	1	Zircon	.753	.819	1	Garnet	.485	.412	1	Microcline	.465	.311
2	Zircon	.192	.276	2	Andalusite	.725	.798	2	Tourmaline	.492	.394	2	Tourmaline	.475	.304
3	Andalusite	.176	.190	3	Calcite	.726	.793	3	Microcline	.495	.374	3	Garnet	.465	.237
4	Garnet	.177	.189	4	Garnet	.758	.761	4	Quartz	.485	.330	4	Hornblende	.550	.167
5	Quartz	.158	.172	5	Tourmaline	.745	.748	5	Sillimanite	.525	.323	5	Sillimanite	.515	.129
6	Microline	.159	.167	6	Quartz	.797	.721	6	Zircon	.490	.312	6	Zircon	.470	.116
7	Tourmaline	.175	.166	7	Sillimanite	.762	.716	7	Hornblende	.525	.304	7	Quartz	.465	.115
8	Hornblende	.122	.147	8	Microcline	.782	.710	8	Andalusite	.475	.290	8	Andalusite	.450	.106
9	Calcite	.117	.138	9	Hornblende	.692	.621	9	Calcite	.470	.260	9	Calcite	.430	.083
	See Figure See Table	1 4			Figure	2			Figure	3			Figure	4	

TABLE 7

Differences between Initial and Average Values

Roundness			Circularity			Mode			Median		
Gains and Losses Most Round			Gains and Losses Most Circular			Most Resistant			Most Resistant		
No.	Mineral	Value	No.	Mineral	Value	No.	Mineral	Value	No.	Mineral	Value
1	Zircon	+ .064	1	Andalusite	+ .073	1	Garnet	.073	1	Tourmaline	.171
2	Sillimanite	+ .071	2	Calcite	+ .067	2	Tourmaline	.086	2	Microcline	.174
3	Hornblende	+ .025	3	Zircon	+ .066	3	Microcline	.121	3	Garnet	.228
4	Calcite	+ .021	4	Tourmaline	+ .003	4	Quartz	.155	4	Andalusite	.339
5	Andalusite	+ .014	5	Garnet	+ .003	5	Zircon	.178	5	Calcite	.347
6	Quartz	+ .014	6	Sillimanite	— .042	6	Andalusite	.185	6	Quartz	.350
7	Garnet	+ .012	7	Microcline	— .072	7	Sillimanite	.208	7	Zircon	.354
8	Microcline	+ .008	8	Hornblende	— .074	8	Calcite	.210	8	Hornblende	.383
9	Tourmaline	— .009	9	Quartz	— .077	9	Hornblende	.221	9	Sillimanite	.386
Least Round			Least Circular			Least Resistant			Least Resistant		

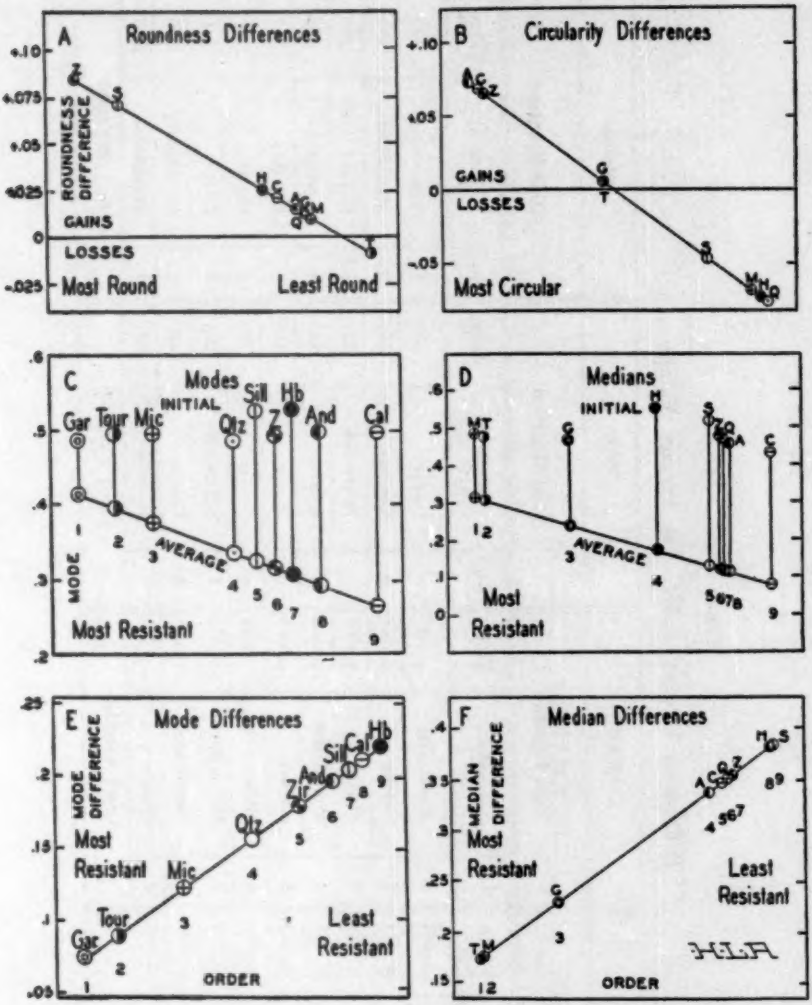


Fig. 5. Comparisons of the nine minerals.

A. Roundness differences; showing gains and losses, differences between initial and average values. Arranged in order of most round to least.

B. Circularity differences showing gains and losses, differences between initial and average values, arranged in order of most circular to least.

occur together with needle-like splinters. The two extremes cancel each other to a large extent in averaging.

Since sorting of grains depends on the shape as well as the size, these two properties together enable nature to separate the larger, rounder grains of quartz from the splinters. It may well be that in some occurrences the high roundness is due to the absence of the splinters perhaps more than it is due to the actual ability of quartz to be well rounded.

There is need for further development of diagrams of roundness of *minerals* of sand size in contrast to pieces of rock of pebble size. The method of Krumbein of determining this property by inspection and optical comparison is very satisfactory. In actual use, however, diagrams based upon minerals, not rock fragments, were found more convenient even though in general the same results were obtained.

RESULTS IN CIRCULARITY

The circularity (projection sphericity) of the nine minerals reveals the independence of the properties of roundness and circularity; the two lists are not the same although there are some similarities. The shape is controlled to a greater extent by the type and kind of cleavage than is roundness. The strength of the mineral plays a role in both.

It can be noted that zircon is high in the list, while tourmaline is in a middle position.

Hornblende, because of the dominance of two cleavage directions, has a low circularity value. The three directions of cleavage in calcite places it high in the list. The differences between the initial and average (column 2 in table 7) values can be divided into two classes: those which increase in circularity due to abrasion and those which decrease. This shows that those minerals with three cleavage directions, in general, increase, while those with none or two directions, with some exceptions, decrease in circularity. Mohs hardness does

---

C. Mode size, initial and average, values arranged in order of decreasing average, most resistant to least.

D. Median size, initial and average values, arranged in order of decreasing average, most resistant to least.

E. Mode size differences, arranged in order of most resistant to least.

F. Median size differences, arranged in order of most resistant to least.

not seem to be an independent factor. It is true that high circularity and high roundness sometimes do go together in nature; while the concepts are separate, the causes of both have something in common.

Under the conditions of the present experiment, quartz has both average and difference values towards or at the bottom of the list. The reason seems to lie in the high splinteriness of the mineral.

FACTORS INVOLVED IN THE MEASUREMENTS

Microscopic.—Nearly twenty-eight thousand grains were measured. The size was measured by means of a camera lucida which projected the image of the grains upon a diaphragm (Alling, 1941), in the opening of which circular scales were fitted, marking off the limits of the class intervals in size ranges. This results in *projection* size. Grain sizes were measured in millimeters as diameters of circles whose areas are equal to the areas of the grains. Whether this is "nominal sectional diameter" and is not applicable to thin sections, as Riley (1941) maintained, is a matter of definition. Does this criticism apply to projection size as well?

The values thus obtained are influenced by the shape of grains for the orientation of the grains is a preferred one. Size so measured is not the same as true three dimensional size. Pettijohn suggests that projection values are of the order of 10 percent too large (1949, p. 407).

Screening mineral fragments is rapid but the results are modified by shape in that long needle-like grains, which according to size would be otherwise retained, are up-ended and pass through. Screening is not strictly three dimensional in operation. This is well known.

Thin sections of sedimentary rocks present random sections of mineral grains, areas of which are measured. Such measurements are two dimensional in that the third is not directly available. If the grains were spheres of uniform size, measurements in thin section would be 76 percent of what they would be in three dimensions (Krumbein and Pettijohn, 1938, p. 130). But the mineral grains are not spheres of uniform size. Hence the corrective factor is only approximately 75 percent. Thus values from thin sections are of the order of 25 percent smaller than they should be.

Metallographic size.—Metallographers measure grain size by a microscope using polished blocks of alloys. Usually size is expressed as the number of grains per unit area. The third dimension is not available. These figures are comparable to measurements from thin sections.

This discussion reveals some of the factors involved in the measurement of grain size. The petrology of sedimentary rocks requires the extensive use of thin sections, hence measurements of grain size in that form should receive more attention.

PROBLEMS OF MEASURING GRAIN SIZE

Pettijohn (1949, p. 9) lists six concepts of size. He says (p. 11) "It is desirable, therefore, that they be codified or standardized." One of the ways to obtain this would be the establishment of the conversional factors on a more quantitative basis. Then conversion from one system to another can be made. Much work reported in the periodicals is of little value because of the multiplicity of methods and the present inability of converting measurements from one scheme to another.

TABLE 8

Approximate Conversion Factors for Size

	Method	Approximate factor	Direction
1	Three dimensional size	100%	0
2	Screening	Variable	Too small for rods Too large for discs
3	Projection size	*110%	+ 10
4	Thin section	**75%	— 25

* Pettijohn (1949, p. 407).
** Krumbein, in Krumbein and Pettijohn (1938, p. 130).

The common approach to this problem seems to be that all measurements should be converted to one hundred percent full size. Those from thin sections are usually regarded by many as "incorrect" and hence of little value. But consider the practice of the metallographer; grain sizes of his alloys

are strictly analogous to that obtained from thin sections. These values are the only ones he has. This does not prevent him from using them, however, even though they are not the "full" value.

Is it not possible that the values of grain size obtained from thin sections are as satisfactory as any other? But they are not so regarded. Is this a good and sufficient reason?

With equal force much the same discussion can be devoted to shape analysis. The methods listed in table 8 all give different values of sphericity. The conversional factors for this property are little known. Pettijohn (1949, p. 400) suggests that in the case of quartz, projection sphericity is 12 percent too large. In the matter of roundness the situation may be similar. This seems to be a fruitful field for further investigation.

In the matter of size, the usual fundamental measurement is that of diameter and the results are plotted in the form of frequency-distribution curves, the ordinate being the per cent by number of grains. (The weight of grains is not directly available from thin sections). In a rock consisting of a few large grains imbedded in a mosaic of smaller ones, the striking thing about it is the large grains, not the small ones. To the eye it is the areas of these large grains that is impressive. There are advantages to the method of measuring and plotting areas of grains rather than diameters. This procedure can be extended to the plotting of the percentage in terms of area rather than by number. This suggests that the multiplicity of methods needs further investigation, not a single method alone but several at a time.

CONCLUSIONS

The laboratory studies of abrasion of sedimentary rock minerals needs further clarification. Pettijohn (1949, p. 389) remarks that "experimental and field studies indicate the process to be very complex." Each mineral presents its own problems. The present paper has shown how each mineral behaves alone. There is no way of predicting how they would act together, using fragments of different hardness and cutting ability on each other. Such mixtures may not give algebraic average results. The rate of reduction in size, roundness, and circularity are all related to size.

All minerals during mechanical abrasion are reduced in size; they can be rounded and the sphericity (and circularity) increased. The rate at which this is accomplished depends upon many factors, a few of which have been investigated. Each of the nine minerals has its own characteristics. Generalizations are not justified at present. The results are shown in the graphs. It is inferred that all minerals possess individual properties which vary with different conditions of abrasion.

This paper suggests that studies of abrasion require the recognition of the peculiarities of each mineral. More attention should be directed to better techniques of grain analysis: size, two dimensional sphericity, and roundness of mineral grains in thin sections of sedimentary rocks.

References

Alling, H. L., 1941. A diaphragm method for grain size analysis: Jour. Sedimentary Petrology, vol. 11, pp. 28-31.

———, 1943. A metric grade scale for sedimentary rocks: Jour. Geology, vol. 51, pp. 259-269.

———, 1944. Grain analyses of sand size in ball mills: Jour. Sedimentary Petrology, vol. 14, pp. 103-114.

———, 1950. Initial shape and roundness of sedimentary rock mineral particles of sand size: Jour. Sedimentary Petrology, vol. 20, pp. 131-147.

Fairbairn, H. W., 1943. Packing in ionic minerals: Geol. Soc. America Bull., vol. 54, pp. 1305-1374.

Fay, Robert L., 1948. Master's thesis, unpublished, University of Rochester, Rochester, New York.

Freise, F. W., 1931. Untersuchung von Mineralen auf Abnutzbarkeit bei Verfrachtung in Wasser: Min. pet. Mitt., vol. 41, new ser., pp. 1-7.

Galloway, J. J., 1919. The rounding of grains of sand by solution: Am. Jour. Sci., 4th ser., vol. 47, pp. 270-280.

Krumbein, W. C., 1941a. Measurement and geological significance of shape and roundness of sedimentary particles: Jour. Sedimentary Petrology, vol. 11, pp. 64-72.

———, 1941b. The effect of abrasion on the size, shape, and roundness of rock fragments: Jour. Geology, vol. 49, pp. 482-520.

———, and Pettijohn, F. J., 1938. Manual of sedimentary petrography, D. Appleton-Century Co., New York.

Levin, S. B., 1950. Genesis of some Adirondack garnet deposits: Geol. Soc. America Bull., vol. 6, pp. 519-565.

Marsland, P. S., and Woodruff, J. G., 1937. A study of the effects of wind transportation on grains of several minerals: Jour. Sedimentary Petrology, vol. 7, pp. 18-30.

Pettijohn, F. J., 1949. Sedimentary rocks, Harper Bros., New York.

———, and Lundahl, A. C., 1943. Shape and roundness of Lake Erie beach sands: Jour. Sedimentary Petrology, vol. 13, pp. 69-78.

Riley, N. A., 1941. Projection sphericity: Jour. Sedimentary Petrology, vol. 11, pp. 94-95.

Rittenhouse, Gordon, 1943. A visual method of estimating two-dimensional sphericity (abstract): Jour. Sedimentary Petrology, vol. 13, pp. 79-81.

Thiel, G. A., 1940. The relative resistance to abrasion of mineral grains of sand size: Jour. Sedimentary Petrology, vol. 10, pp. 103-124.

———, 1945. The mechanical effects of stream transportation on mineral grains of sand size (abstract): Geol. Soc. America Bull., vol. 56, p. 1207.

Wadell, Hakon A., 1935. Volume, shape and roundness of quartz particles: Jour. Geology, vol. 43, pp. 250-280.

Wentworth, C. K., 1932. *In* Treatise on sedimentation, W. H. Twenhofel, Editor, 2d ed., The Williams and Wilkins Co., Baltimore.

University of Rochester
Rochester, New York.

[American Journal of Science, Vol. 249, August, 1951, Pp. 591-599]

THE USE OF THE TERMS PITCH AND PLUNGE

R. H. CLARK and D. B. McINTYRE

ABSTRACT. Attention is called to the fact that "pitch" and "plunge" are used in varied senses by different authors. "Pitch" appears to have been used originally as a measure of the obliquity of ore-shoots in the plane of the vein. Since 1906, "plunge" has been used as an angular measure in a vertical plane. Tectonicians are today seeking terms for concepts whose nomenclature was standardised by mining engineers forty years ago. It is highly desirable that the established usage should be continued in this new sphere. Application of the terms to igneous and granitic bodies is briefly dealt with; the nomenclature of folds is discussed in more detail.

GENERAL

WHEREAS the orientation of a coal-seam is given by its dip and strike alone, in metal mining, not only is the position of the vein to be defined, but the obliquity of the ore-shoot on the plane of the vein is also to be determined. The direction of maximum elongation, or "pitch-length," of an ore-shoot may be defined, independently from the vein in which it is contained, by means of two co-ordinates: *viz.* (i) the bearing of the projection of the pitch-length on a horizontal plane, and (ii) the vertical angle between the pitch-length and the horizontal. These co-ordinates, however, are not normally employed by mining engineers. The underground worker naturally refers all data to the plane of the vein in which the ore-shoot lies; *e.g.* in a vein striking north-south, an ore-shoot is said to "pitch" either north or south, whatever either its obliquity to the strike, or the dip of the vein may be. In short, the obliquity of the shoot is measured from the horizontal, *in the plane of the vein.*

As early as 1868, G. H. Cook noted that the term "pitch" had come into use among those engaged in iron mining to denote the obliquity of the long axis of elongated iron-ore bodies with reference to the bedding. Unfortunately his definition is inconsistent and there are certain ambiguities in his diagrams. It is clear, however, that he was endeavouring to describe a linear structure lying on a plane. The strike of the plane (N 45° E) can be estimated from the sketch map, and its dip (55° to the southeast) from the "cross-section" at right angles to the strike. Further, a "section," the inclina-

tion of which was not stated, was included to show the angle of "pitch" (35° to the northeast). As this "section" contains both the lineation and the strike of the plane, it follows that Cook measured "pitch" on an *inclined plane*. Thus, in Cook's example, the co-ordinates (mentioned above) of the linear structure are, (i) N 65° E, and (ii) 28° to the northeast. Elsewhere, however, the same author used "pitch" for a measurement in a vertical plane. The need for separate terms for these two different angles did not merge until forty years later.

In 1908, Professor H. Louis of Armstrong College, Newcastle, called attention (Raymond *et al.*, 1908) to the absence of any recognised English term for the vertical angle between the pitch-length and the horizontal, and proposed that "pitch" should be used for this. R. W. Raymond, of New York, objected to this proposal (1908). According to Raymond, the "practically universal" usage of American mining engineers was to measure "pitch" on the plane of the vein. He had himself used "pitch" in this sense for forty years prior to 1908, and he believed that there was no instance to the contrary in the twenty-seven volumes of the Transactions of the American Institute of Mining Engineers that he had edited. In the discussion which followed, all contributors agreed that Raymond's usage had been standard practice for many years amongst American mining engineers.

It was obvious, however, that it had become necessary to have two terms; one was required for each of the two angles in question. "It is evident," wrote Raymond, "that if Professor Louis's definition of 'pitch' were accepted, what I call 'pitch' would need a new name—and *vice versâ;* and it is probable that the question which pitch should hereafter be the standard pitch would be largely affected by the extent of the present intelligent usage." While Louis naturally preferred his own use of the term, he wrote, "I do not think that it matters very greatly which definition of pitch we adopt; the essential thing is that we shall definitely decide upon one, and keep to it."

The man most keenly interested in pitch was the practising engineer engaged in metal mining, and, for him, Raymond's angle, measured in the plane of the vein, was more convenient than Louis', measured in the vertical plane contain-

ing the pitch-length. For this reason, as is now a historical fact, the following usage has become standard (Lindgren, 1933, pp. 155-156; Bateman, 1942, p. 133):

> With reference to a linear structure *contained in a plane,*
>
> *Pitch* is the angle between the lineation and the horizontal, as measured in the plane (angle DAC in text-fig.).
>
> *Plunge* (the term for Louis' angle suggested by H. L. Smyth in 1908) is the vertical angle between the lineation and the horizontal (angle ACE in text-fig.). In a certain sense it may be said that plunge is thus the special case in which pitch is measured in a vertical plane.
>
> *Trend* is the strike of the vertical plane containing the lineation (CE in text-fig.).

Structural geology is a young science. Even in 1937, R. Balk, in a specialised memoir, found it necessary to devote several pages to demonstrate that a preferred orientation of crystals, seen on a random surface, might represent the trace of either a planar or a linear arrangement in the rock. In fact, in endeavouring to define the position of either a lineation on an *s*-surface, or a trace on a random plane, we encounter today precisely the same requirements in nomenclature as did our mining colleagues over forty years ago. It seems clear that we should recall Louis' advice and act on it. Having definitely decided upon our nomenclature, it is essential that we should keep to it.

With reference to a particular type of lineation, mining

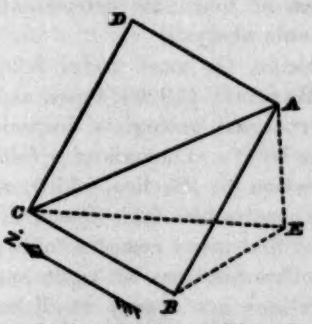


Fig. 1. Isometric projection, showing position of plane of bed or vein, and axis of ore-body therein. ABCD, plane of vein; AC, axis of body; AE, vertical; BC, CE and BE, horizontal. (Figure and explanation after Louis and Raymond, 1908).

engineers, for more than eighty years, have used "pitch" for an angle measured in a plane, vertical only in a particular case. Now that the need to define other types of lineation has arisen, it would be folly to restrict "pitch" to angles measured solely in this special case. It is always somewhat perilous, as Raymond pointed out in 1908, to restrict the meaning of a term previously used in a wider sense. Moreover, if "pitch" were thus restricted, a new term would be required. The term "pitch" cannot, of course, be used in different senses when applied to different types of lineation. There is here no dilemma; the terms established by mining engineers in the course of nearly a century of practice fit our requirements perfectly. Either we take advantage of the experience of our mining colleagues, or we invent a parallel set of completely new terms with the same definitions. Any other course will lead to chaos. To invent new terms for angles already carefully defined will serve no useful purpose, and, indeed, many leading tectonicians in the English-speaking world have already adopted the definitions given above (*e.g.* Billings, Bucher, Nevin, and others).

APPLICATION TO FOLDS

Although folds are three-dimensional structures, they have, in most cases, an important linear aspect. In any highly folded region, and in particular in a segment of a geosynclinal chain, the folds are found to be conspicuously elongate. The direction in space of this elongation is referred to as the *axis* of the fold or system of folds. Its determination is a primary requisite for tectonic analysis.

For the tectonician, the most useful definition of fold-axis is that given by Wegmann (1929), based as it is on the usage of the Alpine structural geologists (especially Lugeon and Argand) since the 1890's. The axis of a fold is defined as the nearest approximation to the line, which, moved parallel to itself in space, generates the fold. The utility of this definition lies in the fact that many complex folds maintain remarkably constant profiles (sections at right angles to the axis) even when the sections are spaced at distances many times greater than the amplitude.

A fold-axis is a linear structure, and, in defining its orientation, our terminology must conform to that used for all other

linear structures. Thus, the pitch of a fold-axis has meaning only when related to the plane on which it has been measured. In practice the plunge of a fold-axis is usually measured directly, but, on occasion, it is more convenient to measure the pitch of the axis on some inclined plane, the dip and strike of which must, of course, be specified. Some authors have used the terms "pitch" and "plunge" synonomously for the vertical angle between the horizontal and the fold-axis; others have used the term "pitch." This differing usage leads to confusion.

Definitions of fold-axis, other than that given above, will be found in most of the current text-books. The majority of these definitions conform, in principle, to one of three different types:—

1. The fold-axis is sometimes defined as "the median line of the fold, along the top of an anticline or the bottom of a syncline." The trend and plunge thus determined are the same as those found when using Wegmann's definition. But, whereas Wegmann's axis is a line with orientation alone, the definition just cited fixes position as well as orientation. This is analogous to requiring that a crystallographic axis must pass through the centre of the crystal; the restriction is unnecessary, and is, indeed, a disadvantage.

2. For some geologists, "an axis of a fold is the line in which any bed intersects the axial plane." The obvious difficulty with regard to this definition is that it is first necessary to define the term "axial plane." Most attempts to do this either have been too vague, or have been so worded that strict application is not possible when the fold-axis (of Wegmann) plunges.

Bonté (1945, p. 35), following Haug and others, defines the *axial surface* as the locus of the hinges of all beds forming the fold. This appears to be the only sound definition possible, and if employed it automatically ceases to be necessary to use axial surface in defining fold-axis. The latter then becomes synonymous with "hinge," *i.e.* with the locus of points of maximum curvature of the cylindroidal surface constituting the fold. Thus, the fold-axis would be fixed in a position which is nearly, but, in the general case, not quite coincident with the median line, *i.e.* with the apex-line or arête.

3. The axis of a fold has been defined as "the line of inter-

section of the axial surface with the topographic surface." Even if "horizontal surface" were to be substituted for "topographic surface," this definition would remain unsatisfactory. (i) There would be no way of indicating the plunge of the fold-axis in Wegmann's sense; (ii) except in a special case, a curved axial surface would necessitate a curved "fold-axis," even although the form of the fold were ideally cylindroidal, and (iii) as Argand (1911) and Wegmann (1929) have emphasised, general strike and axial trend, in the sense of Wegmann, coincide only in a limiting case.

It seems clear that Wegmann's concept and definition of the axis as the generatrix of the fold is the most logical proposed. It is a linear structure and the terms pitch and plunge with reference to it must be used in the same way as for all other linear structures.

To the proposals made here, it may be objected that the term "plunging" has already been used to denote downward closure at the hinge of a recumbent anticline. Bailey and McCallien (1937, fig. 1), and Bailey (1939, fig. 51) have published a diagram in which this use of the term is implied. Although no definition is given by these authors in their texts, it appears inherent in their diagram that, for them, an anticline is said to be "plunging" where it is a synform. Thus, before the term may be applied to a specific fold, it is necessary to establish that it is in fact an anticline (*sensu stricto* of Bailey and McCallien). The term is apparently limited to terrains where the stratigraphy is unravelled.

For more than half a century, Alpine geologists have recognised examples, not only of recumbent folds, but of folds whose axial surfaces (see definition above) have locally been rotated through more than a right angle from their presumably vertical, original positions. These folds are the "false anticlines" and "false synclines" of Lugeon, Haug, and others. Perhaps the best known illustration is Lugeon's diagrammatic stereogram of the structural units of the Tatra (1903, fig. 1). The use in French of the adjective "plongeant" for such folds, may have influenced the choice of the term "plunge" by British geologists. It should, however, be realised that, in French, the same term may apply, not only to the "plunging anticline" of Bailey and McCallien, but to the dip of a bed,

or to the "plunge" of a fold-axis, in our sense. For examples of the latter usage we may cite Lugeon's classic Memoir on the Origin of the Valleys of the Western Alps (1901).

When we refer to the "plunge of a fold-axis" (in our sense), we imply, and in general specifically state, a quantitative measure. On the other hand, Bailey and McCallien, in describing a "plunging anticline" have indicated no way in which the amount of "plunge" is to be measured. The measure which suggests itself is as follows:—

The amount of "fold-plunge" along any specified line on the axial surface is given by the angle, as measured on the profile plane (*i.e.* the plane at right angles to the fold-axis), between the horizontal and the tangent to the axial surface along the line specified.

According to this measure, a recumbent fold would have zero "fold-plunge". It would be, of course, possible to determine "fold-plunge" only along a specified hinge-line.

All this, however, exposes the weakness of the term "fold-plunge." *Plunge* is an angular measure in a vertical plane. *Pitch* is used when a linear structure is related to the inclined plane on which it is measured. The value of Bailey and McCallien's "plunge" obviously depends on the axial-plunge of the fold, and it is therefore a typical *pitch* measurement and not a *plunge*. For this reason it is suggested that, if it is felt necessary to specify Bailey and McCallien's "fold-plunge," it be measured and given as *fold-pitch* and be stated together with the *axial-plunge*, without which it has no meaning.

Whereas the concept of Bailey and McCallien refers to the form of the fold in profile (*i.e.* in transverse section), axial-plunge denotes the inclination of the longitudinal section. There is, therefore, no reason why the two should not be used side by side, and, indeed, they have thus been used in numerous instances in the literature (see for example Lugeon, 1902).

APPLICATION TO IGNEOUS AND GRANITIC BODIES

In an igneous or granitic body, a preferred orientation of crystals, observed on a random plane, may represent the intersection with that plane of a linear, a planar, or a cylindroidal arrangement of the crystals within the rock mass, or a combination of these arrangements. It is suggested that the term

"trace" is to be preferred to "lineation," "apparent lineation," or "mineral parallelism" when reference is made to observations on a random plane. The method of distinguishing between the traces of linear and planar structures will be discussed in another publication.

It may sometimes be convenient to measure the plunge of a trace directly. But, as a trace has no meaning except when related to the plane on which it has been observed, it is more logical, and usually more convenient, to record the obliquity of the trace on the plane of the exposure as a *pitch*.

CONCLUSIONS

It is necessary to have separate terms to refer to each of the following:—

1. The angle between a line and the horizontal as measured in some specified plane containing the line.
2. The vertical angle between a line and the horizontal.

This case is a limiting example of the first.

Discussion of the different usages of the terms *pitch* and *plunge*, due consideration having been given to the question of precedence, has led to the conclusion that the most logical system of nomenclature at the present day is to adopt the former for the first angle and the latter for the second. The following definitions are therefore offered:—

Pitch is the angle, measured in some specified plane, between a lineation, or a trace, and the horizontal.

Plunge is the vertical angle between a lineation, or a trace, and the horizontal.

Trend is the strike of the vertical plane containing a lineation or a trace.

References

Argand, E., 1911. Les nappes de recouvrement des Alpes Pennines et leurs prolongements structuraux: Beitr. geol. Karte Schweiz, n.s., vol. 31, pp. 1-26.

Bailey, E. B., 1939. *In* Introduction to geology, E. B. Bailey and J. Weir, Macmillan Company, New York.

———, and McCallien, W. J., 1937. Perthshire tectonics: Schiehallion to Glen Lyon: Royal Soc. Edinburgh Trans., vol. 59, part 1, pp. 79-117.

Balk, R., 1937. Structural behavior of igneous rocks: Geol. Soc. America Mem. 5.

Bateman, A. M., 1942. Economic mineral deposits, John Wiley & Sons, Inc., New York.

Billings, M. P., 1942. Structural geology, Prentice-Hall, Inc., New York.

Bonté, A., 1945. Introduction à la lecture des cartes géologiques, Masson et Cie., Paris.

Bucher, W. H., 1944. The stereographic projection, a handy tool for the practical geologist: Jour. Geology, vol. 52, pp. 191-212.

Cook, G. H., 1868. The geology of New Jersey, New Jersey Geological Survey, Newark.

Lindgren, W., 1933. Mineral deposits, McGraw-Hill Book Company, New York.

Lugeon, M., 1901. Recherches sur l'origine des vallées des Alpes occidentales: Annales de géographie, vol. 10, pp. 295-317, 401-428.

———, 1902. Sur la coupe géologique du massif du Simplon: Soc. géol. France Compte rendu sommaire (March 24), vol. 134, pp. 726-727, 792.

———, 1903. Les nappes de recouvrement de la Tatra et l'origine des Klippes des Carpathes: Soc. vaudoise sci. nat. Bull., 4th ser., vol.39, pp. 17-63.

Nevin, C. M., 1949. Principles of structural geology, John Wiley & Sons, Inc., New York.

Raymond, R. W., et al., 1908. Dip and pitch: Am. Inst. Min. Eng. Trans. (1909), vol. 39, pp. 326-327, 898-916.

Wegmann, E., 1929. Beispiele Tektonischer Analysen des Grundgebirges in Finnland: Comm. géol. Finlande Bull., vol. 87, pp. 98-127.

University of Edinburgh
Edinburgh, Scotland

[American Journal of Science, Vol. 249, August, 1951, Pp. 600-603]

A CLYMENOID AMMONOID FROM NEW MEXICO

A. K. MILLER and CHARLES COLLINSON

ABSTRACT. Clymenoids, which are characteristic of the Upper Devonian, are of widespread occurrence in the eastern hemisphere but are rare indeed in the western. A specimen recently found in the Percha shale of New Mexico belongs in *Falciclymenia* Schindewolf, previously known from only the genotype, *F. falcifera* (Münster) of Oberdevonstufe III of western Europe. Therefore, it can be said to indicate that the Percha is rather late Upper Devonian in age.

DURING the 1949 field season Mr. A. L. Bowsher of the United States National Museum secured a peculiar cephalopod from the Percha shale of southwestern New Mexico, and Dr. G. Arthur Cooper of the same institution kindly made it available to us for study. This specimen belongs in the small group of aberrant Upper Devonian ammonoids known as clymenoids or the Intrasiphonata, as they have dorsal siphuncles. Representatives of that suborder are of local abundance and widespread occurrence in the eastern hemisphere, being known from many widely separated localities in Europe, Asia, Africa, and Australia. However, only three species have been described from the Americas: *Acanthoclymenia neapolitana* (Clarke) of the Naples group of New York, and *Platyclymenia* (*Pleuroclymenia*) *americana* (Raymond) and *P.* (*P.*) *polypleura* (Raymond) of the Threeforks shale of Montana.

The specimen from New Mexico is not similar to any of these species, but it is closely related to *Goniatites falcifer* Münster [not of Kayser] of Oberdevonstufe III in northeastern Bavaria (Schübelhammer) and southern France (Cabrières)—illustrated by Münster (1840, plate 16, fig. 7). In 1923 Schindewolf made that species the type of a genus, *Falciclymenia*, to which no other forms have been referred. Although it seems to us that the Percha specimen should be regarded as congeneric with *F. falcifera*, it represents a distinct species, which we propose to name in honor of its discoverer.

Falciclymenia bowsheri, n. sp.

Most of the more significant characters of the individual on which this species is based are elucidated by the accom-

panying illustrations. However, it should be stated that the holotype is moderately well preserved in dense light-gray limestone and that the side of it that is not figured is considerably "worn." Its maximum overall measurement is about 67 mm., and near its adoral end the height and width of conch are about 43½ mm. and 21 mm., respectively. No trace of the surface ornamentation (nor of the siphuncle) can be discerned on this specimen, an internal mold.

The umbilicus was open and moderately large, resembling that of the genotype but having a somewhat greater diameter. Although both the internal and the external sutures are also similar to those of that species (as illustrated by Schindewolf, 1923, p. 28, text fig. 4f), they differ in detail. In *F. bowsheri* the ventral saddle is relatively large and blunt—Schindewolf has written us that the conch of *F. falcifera* is acute ventrally—and the dorsal flank of the lateral lobe is much more

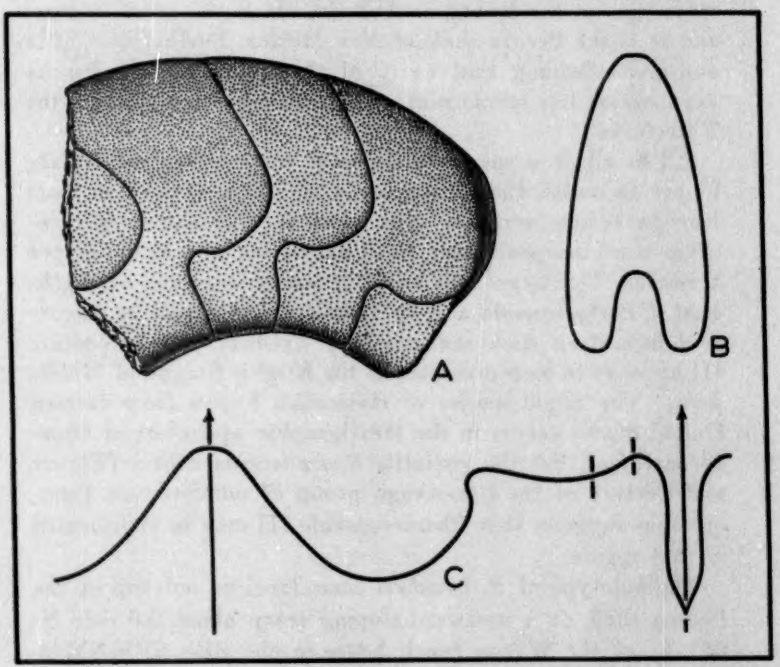


Fig. 1. The holotype of *Falciclymenia bowsheri*, n. sp., X 1 (A and B) and X 1½ (C). The cross section and the suture drawing are diagrammatic.

strongly sigmoidal due to a reversal of curvature. Furthermore, in the American form the umbilical seam is not in the center of the umbilical lobe, as it is in the German one. Although the dorsal portion of the specimen we are studying is not particularly well preserved, the lobe of the sutures there seems to be narrower than is that of the type species.

In 1923 Schindewolf gave the horizon of *F. falcifera* as Oberdevonstufe IV. However, it has now been established that there are only five recognizable ammonoid zones or stages in the classical Upper Devonian of Germany; and, as explained by Teichert (1943, p. 83), "in papers published prior to 1938 Stage IV corresponds to the upper part of Stage III as here understood." In other words, *F. falcifera* occurs in the upper portion of Oberdevonstufe III, the *Prolobites-Platyclymenia* stage. Inasmuch as the Threeforks shale of Montana contains *Platyclymenia*, that formation is presumably of about the same age as the European beds in which the genus occurs, and so is the Percha shale of New Mexico. Furthermore, it is our understanding that many of the species of the Percha are more or less reminiscent of some of those known from the Threeforks.

All in all, it seems quite probable that during rather late Upper Devonian times there was open-water connection from Europe across northern Asia into the Cordilleran geosyncline, much as postulated by Teichert for the early Upper Devonian. This hypothesis would of course be greatly strengthened if *Platyclymenia* and/or *Falciclymenia* should be discovered in eastern Asia—as noted by Teichert, Oberdevonstufe III appears to be represented in the Kirghiz Steppe of Middle Asia. The single species of clymenoids known from eastern United States occurs in the stratigraphic equivalent of Oberdevonstufe I, but the goniatite *Sporadoceras milleri* (Flower and Caster) of the Conewango group of northwestern Pennsylvania suggests that Oberdevonstufe III may be represented in that region.

The holotype of *F. bowsheri* came from an outcrop of the Percha shale on a westward sloping scarp about 0.6 mile N. 65° E. of the Wilson ranch house in the SE¼SE¼NW¼ sec. 11, T. 18 S., R. 7 W., Hillsboro quadrangle, Sierra County, New Mexico.

Acknowledgment is due to Professor O. H. Schindewolf of the Universität Tübingen and Dr. G. Arthur Cooper of the United States National Museum, who read and criticized our manuscript. The accompanying drawings were made by Mr. Howard Webster of Iowa City.

References

Miller, A. K., 1938. Devonian ammonoids of America: Geol. Soc. America Spec. Paper 14.

Münster, Georg, 1840. Die Versteinerungen des Uebergangskalkes mit Clymenien und Orthoceratiten von Oberfranken: Beitr. Petrefacten-Kunde von Herm. v. Meyer u. Georg Graf zu Münster, Heft 3, pp. 33-121.

Schindewolf, O. H., 1923. Entwurf einer natürlichen Systematik der Clymenoidea: Centralbl. Mineralogie, etc., pp. 23-30, 59-64.

Teichert, Curt, 1943. The Devonian of Western Australia, a preliminary review: Am. Jour. Sci., vol. 241, pp. 69-94, 167-184.

State University of Iowa
Iowa City, Iowa

[American Journal of Science, Vol. 249, August, 1951, Pp. 604-616]

RESEARCH ON THE CONTINENTAL NEOGENE OF MEXICO

A. R. V. ARELLANO*

ABSTRACT. Several geologists and geographers from the United States are collaborating with Mexican workers studying the continental Cenozoic deposits of Mexico. Significant finds of vertebrate fossils are helpful in dating formations and in determining geographic conditions of late Cenozoic time. Other fields of research in progress include Pleistocene glaciation, ancient soils, pollen recovered from various depths, and dating of peat by radiocarbon analysis.

BACKGROUND

WHEREAS marine formations are usually distinctive across many tens and even hundreds of kilometers on lithologic or fossil evidence, continental formations are, strictly speaking, restricted to their topographic basins. This entails such a high degree of detailed correlation that studies of valley fills have necessarily lagged.

In the Mexican highlands these studies have been conducted on a very empirical basis for want of good stratigraphic standards. The paleontological reviews of Cope and Freudenberg for a long time supplied the only authoritative time markers in the entire continental Neogene. Edward Drinker Cope visited Mexico in the early eighties and examined fossil mammals at the School of Mines, at the National Museum, at the Scientific Institute of Toluca, at the Colegio del Estado in Guanajuato and in many private collections; he went also to the Pliocene locality Zacualtipan and collected, either in the field or from local residents, the specimens that he later described. Wilhelm Freudenberg worked for the Geological Institute of Mexico in 1905-1906 and apparently labeled the bulk of its fossil mammal collections.

RECENT WORK

In 1922 Furlong revived interest in these problems by extensive collecting at the famous Tequixquiac locality; shortly thereafter, Dr. Childs Frick financed another expedition to the same place by Gonzalo Vivar and Alicia Reyes, members of the Geological Institute of Mexico. Some ten years

*Published with permission of the Director, Geological Institute of Mexico. Financial assistance of Petróleos Mexicanos is gratefully acknowledged.

later Chester Stock, of the California Institute of Technology, began a systematic search for new fossil vertebrate localities in northern Mexico and found in Chihuahua the rich bone deposits which will be known to science as the Yepómera Pliocene fauna (Drescher, 1939; Furlong, 1941; Lance, 1950; Miller, 1944; Stock, 1948; Wilson, 1937a,b), and in Nuevo León the spectacular cave of San Josesito which is a perfect ossarium of Pleistocene life. He also helped the Geological Institute of Mexico to enlarge its collections, notably by presenting in March 1950 a complete mounted skeleton of *Equus conversidens* Owen, subsp. nov. *leoni* Stock from San Josesito Cave. The typescript describing this new subspecies was also presented at this time for publication by our Institute. Stock's continued interest in the fossil mammalian faunas of central Mexico has been evidenced by his sending in July, 1950, two of his students, Richard Tedford and Robert Shultz, to the Goleta area for a general reconnaissance.

In June of 1950 Claude W. Hibbard of the University of Michigan submitted to the Geological Institute of Mexico for publication a paper on the mammalian fauna of the Pleistocene of Mexico which he was able to study during the summer of 1949. He carried on this work as guest lecturer and research associate of the Institute. This paper contains important contributions to the knowledge of the Pleistocene horses and larger ruminants of North America. It is the most comprehensive treatment the Mexican Pleistocene horses have received and will no doubt greatly improve their stratigraphic value. The large bison is determined as *B.* (*Platycerobison*) *chaneyi* Cook and not *B. latifrons*, as it had been called for a long time; a smaller bison is called *B. occidentalis*, being the first time this species has been found so far south. A very interesting discovery concerns an old museum specimen which Hibbard considers is *Euceratherium collinum*, a sheep-like Pleistocene form.

The Associates of Tropical Biogeography, led by Carl O. Sauer of the University of California, are engaged in a study of physical and biological factors that may have affected man from his earliest occupation of this continent. One of the areas which has been selected for detailed study is the arid barrier which stretches across northern Mexico from Durango to Saltillo. This entails working out the lake history

of the Torreón area, generally known as La Laguna, one of Mexico's most prosperous agricultural communities. John Vann, physiographer, and Philip Wagner, plant ecologist and linguist, graduate students at the University of California,

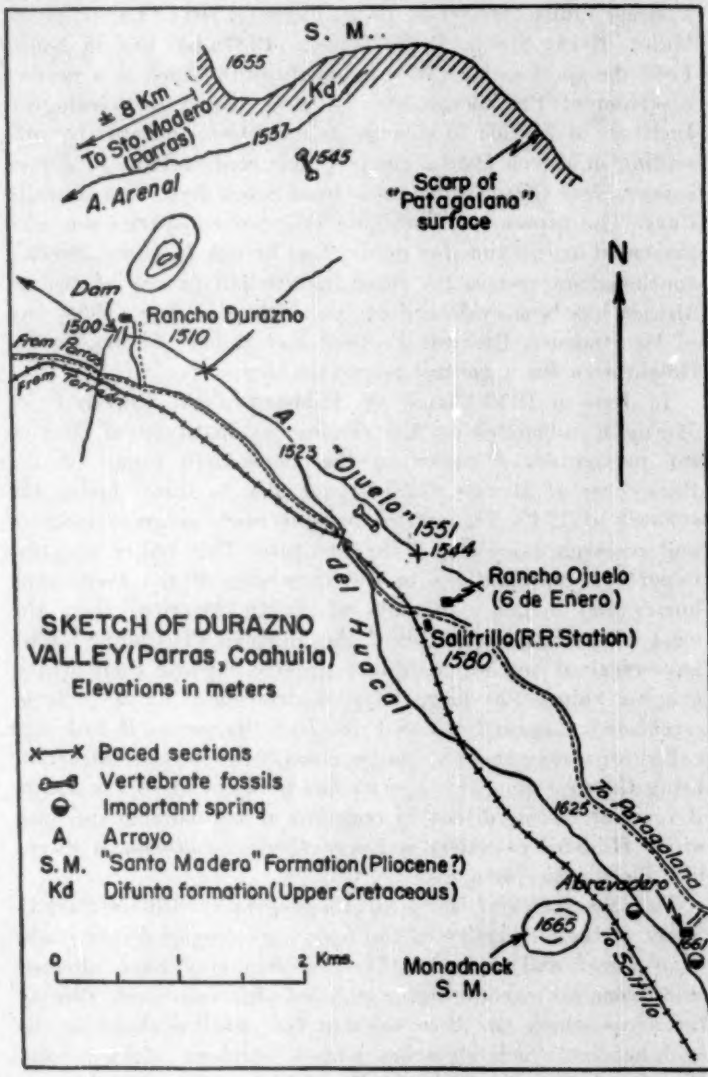


Fig. 1

were selected to carry through the project. Sauer and Arellano spent two weeks introducing them to the area.

Preliminary results indicate that the vicinity of Parras, Coahuila, may be of the greatest significance. In the Arroyo del Huacal and its confluent, Arroyo de Ojuelo, some 8 km. east of town, the following sequence of fossil soils parallels closely the standard for the Mexico City Basin (fig. 1; fig. 2 III). Thicknesses and descriptions are "average" for the section measured. The beds are nearly horizontal.

0.5-1.0 m.	Living soil. Undifferentiated pale gray loam, much eroded. HCl reaction strong, but no appreciable paedocal.
0.5-1.5 m.	Buried humic soil, dark gray. Comparable to "Totoltsingo soil." Upper and lower contacts straight and transitional. HCl reaction strong, but no appreciable paedocal.
2-8 m. (rarely up to 7 m.)	Light brown silt with scattered gravel, locally forming pockets, has moderately hardened relict soil structure. HCl reaction strong but paedocal not conspicuous. Looks correlative with the Becerra.
	ABRUPT AND STRAIGHT CONTACT
2-6 m.	Very light greenish-yellowish clayey silt with strong paedocal (caliche), mostly in stringers and nodules, but locally forming a solid bank up to 0.5 m. thick; contains numerous gravel lenses and mud flows more or less markedly limonitized, which at times suggest the Tacubaya weathering. Elephant teeth have been reported from this bed which otherwise should be correlated with the greenish caliche-laden formation under the chief Becerra bone bed at Tequixquiac.
	STRONG ANGULAR DISCORDANCE
Bedrock	Steeply dipping Difunta (Upper Cretaceous), thin-bedded, calcareous sandstone and marl.

The area is not quite as dry as the plain directly north known as Barrial de la Paila nor as the hills farther north and northeast called Sierra de la Paila. This is evidenced by moderate pine growth on the higher slopes of Sierra de Parras, immediately to the south, as well as by the strong springs that issue from that Sierra into the Parras area. Hence, the lack of a conspicuous paedocal in the actual and buried profiles, excepting the lowest formation, is not unexplainable, for the same relation may have existed through the late Pluvials.

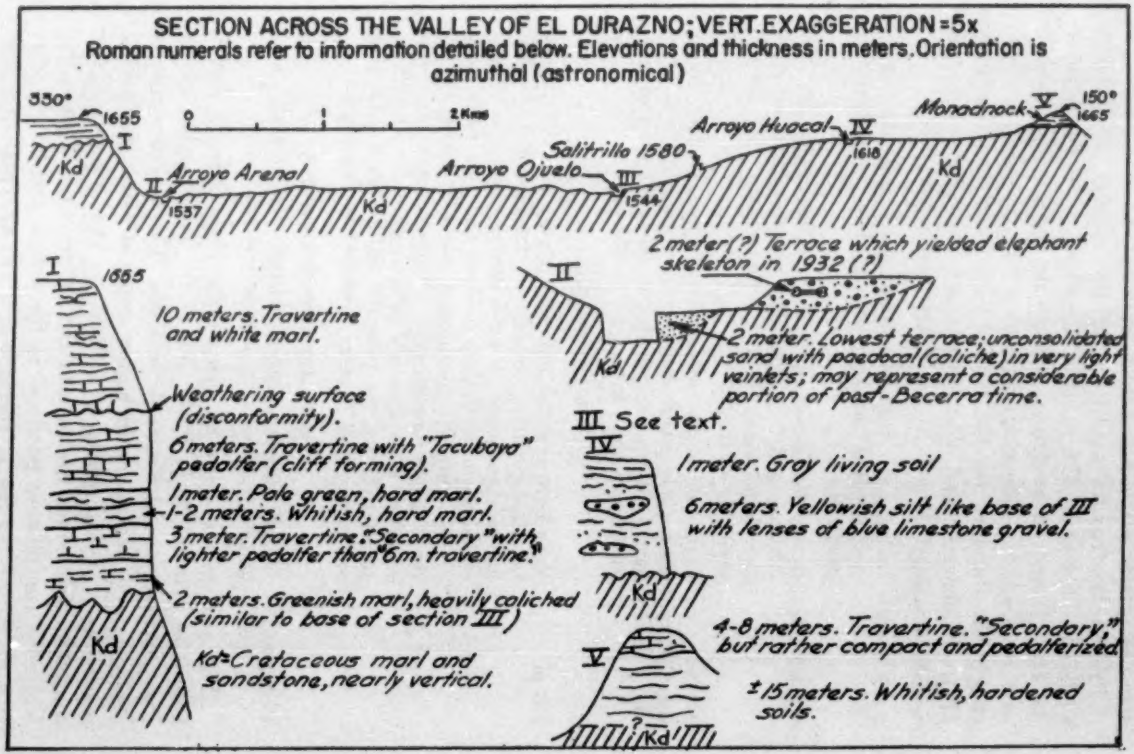

SECTION ACROSS THE VALLEY OF EL DURAZNO; VERT. EXAGGERATION = 5x
Roman numerals refer to information detailed below. Elevations and thickness in meters. Orientation is azimuthal (astronomical)
330°
1655
0
1
2 Kms
I
Kd
II
Arroyo Arenal
1537
Kd
Arroyo Ojuelo
III
1544
Salitrillo 1580
Arroyo Huacal
IV
1618
Kd
Monadnock
V
150°
1665
I
1655
10 meters. Travertine and white marl.
Weathering surface (disconformity).
6 meters. Travertine with "Tacubaya" pedolfer (cliff forming).
1 meter. Pale green, hard marl.
1-2 meters. Whitish, hard marl.
3 meter. Travertine: "Secondary" with lighter pedolfer than "6m. travertine."
2 meters. Greenish marl, heavily coliched (similar to base of section III)
Kd
Kd = Cretaceous marl and sandstone, nearly vertical.
II
2 meter (?) Terrace which yielded elephant skeleton in 1932 (?)
2 meter. Lowest terrace; unconsolidated sand with paedocal (caliche) in very light veinlets; may represent a considerable portion of post-Becerra time.
Kd
III See text.
IV
1 meter. Gray living soil
6 meters. Yellowish silt like base of III with lenses of blue limestone gravel.
Kd
V
4-8 meters. Travertine. "Secondary," but rather compact and pedolferized.
± 15 meters. Whitish, hardened soils.
? Kd

Fig. 2

The fossil record for southern Coahuila is very poor, in spite of the fact that numerous isolated finds of elephant, horse, etc., are known. In our brief survey it was not possible to find any bone in place, but the two fossil localities marked on the accompanying sketches (figs. 1,2) are well authenticated. The one on Arroyo del Arenal refers to what must have been a nearly complete elephant skeleton excavated by engineers Gabriel Madero and José Treviño García about 1932 (?). Photographs taken during the excavation were shown us by Treviño García. The Arroyo Ojuelo find was reported by archeologist Antonieta Espejo; it included scattered molars, which we examined at the Parras Escuela Secundaria Federal, and limb bones.

From what is known of the migration of the elephants they must have flourished in southern Coahuila earlier than in central or southern Mexico; therefore, even granting that elephant teeth occur in the greenish-yellowish layer, we should still consider it somewhat older than the elephant-horse fauna of the typical Becerra. At present the latter may be considered as possibly extending back to Illinoian and hence the greenish-yellowish layer could represent Kansan time. The heavy caliche must have been formed during the prolonged Yarmouth interval, at which time the elephants perished or were driven south to less stricken areas.

During the earliest Pleistocene (Nebraskan-Aftonian) the streams excavated deeply into the Pliocene (?) Santo Madero travertine formation. The immediate cause for this active erosion was the tilting upward of the foothill area north of Sierra de Parras. This tilting exceeded 100 m. and may have reached close to 400 m. or the difference in elevation between Paila and Santo Madero, a distance north-south of about 20 km.

A particularly clear proof of this tilting is seen on the southwestern edge of the town of Parras, where the shrine "Santo Madero"[1] is perched on a crag of massive travertine about 17 m. thick. Underneath are quasivertical marl and

[1] This is the type locality for the travertine formation which we are calling "Santo Madero." When the Mayrán formation of R. W. Imlay is restricted properly, the term "Santo Madero" may become superfluous as a formation, but might be retained as a facies designation.

calcareous sandstone of the Upper Cretaceous "Indidura"[2] with a fairly flat, though very irregular contact, along which are rounded boulders up to 0.3 m. of marine limestone from the Sierra de Parras to the south. Some 300 m. and 400 m. respectively, in a NNE direction, are two small knobs, the first of which is formed by an indurated marly silt which may be an old paedocal, whereas the second consists of about 5 m. of travertine which in its southern edge rests on the "Indidura," though elsewhere it overlies 0.5-1.0m. of an indurated whitish silt similar to that capping the first knob. The bottom of the travertine at the second knob dips 10° NE, and if this plane be projected to the Santo Madero crag it would pass very close to the base of its travertine (fig 3). Initial dip does not seem a logical explanation, because it is the only place in the area where dips of that magnitude occur in the travertine beds.

The section across the Valley of El Durazno (fig. 2) shows that the younger deposits occupy trenches carved out of the higher Santo Madero travertine and of the underlying Cretaceous. This leaves very little doubt of the greater age of the travertine formation (or formations) which we differentiate by the name "Santo Madero," relative to the Huacal-Ojuelo section which we have tabulated.

It should be emphasized that no real travertine[3] was seen in the Huacal creek below Salitrillo, nor in the extension of Ojuelo creek which we paced. Above Salitrillo, close to Abrevadero, about 15 liters per second of water issue from "secondary" travertine,[4] below what we consider the local equivalent of the Huacal-Ojuelo section, at each of two springs.

[2] The three Upper Cretaceous formations recognized by Imlay in this area are, upwards, Indidura (probably a misspelling of "Hendidura"), Parras, and Difunta. Lithologically, "Indidura" and "Difunta" are much alike.

[3] We use travertine in a restricted sense for compact carbonate rock, frequently with algal indications, rarely containing clastics, in beds of very considerable lateral extent, but seldom exceeding a few meters in thickness. Heavy calcareous developments in nodular, or even tabular form, but in which relict soil structure may still be seen, would be definitely excluded. The compactness and usual purity of travertine have caused it to be confused with marine limestone where both outcrop in the same area.

[4] The term "secondary" travertine is here used to denote a porous mass of carbonate rock most of which has the aspect of lime evaporite formed in caves; it therefore implies that this mass was real travertine but has lost its "primary" texture by solution and redeposition of its carbonate by circulating ground-water.

It would then seem that the largest lake in the structural trough between Torreón and Saltillo existed in the Pliocene and that its dimensions were much reduced during the Pleistocene pluvials. The more obvious cause was the cantilever tilting during late Pliocene or early Pleistocene of the northern foothill zone of the Sierra de Parras, whereby the more southerly portion was raised from 100-400 m. relative to the bottom of the trough. At present the outlets of this trough appear to be at about 1,400 m. toward the east (railroad pass to Monclova) and at about 1,500 m. toward the north (road to Cuatro Ciénagas).

There is also the possibility that the shrinking of the Pleistocene lakes may have been further accentuated by the prolonged interpluvials which were not compensated by the pluvials.

RADIOCARBON (C^{14}) DATINGS

Dr. Helmut de Terra, financed by the Viking Fund, submitted a selected suite of specimens to the Institute for Nuclear Studies of the University of Chicago, where Dr. W. F. Libby has succeeded in developing the first reliable routine for dating radiocarbon (C^{14})-bearing objects. Two of these samples were collected by Arellano in 1945 from the Armenta horizon (a beach-swamp feature within the

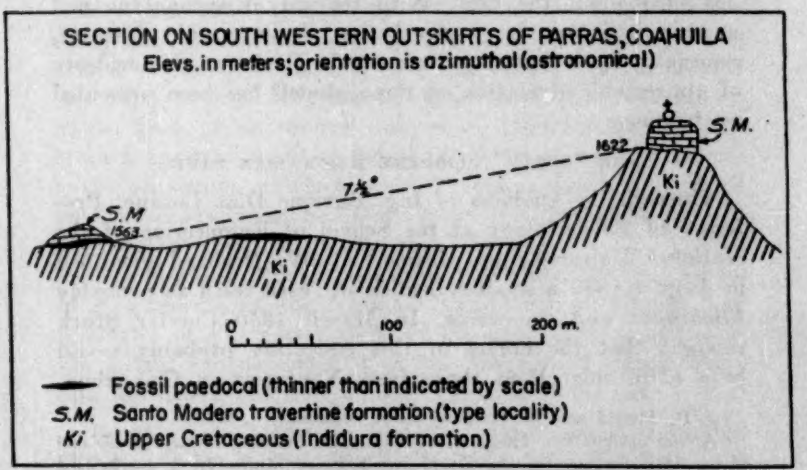


Fig. 3. The section extends from 20° at left to 200° at right.

Becerra formation). One of these was a stump of a *Taxodium*-like tree in perfectly fresh condition (no apparent mineralization, carbonization, or physical decay) which gave an age of "older than 16,000 years." The second was a composite sample of peat from the same Armenta horizon (about 2 m. thick at locality of sample) which gave an age of "11,000± 500 years."[5]

The difference in age may mean that the duration of swampy conditions at that place lasted over 5,000 years. The fact that the exact position occupied by the peat sample within the Armenta horizon is unknown detracts from the value of this result.

We are planning to submit to the University of Michigan Paleontological Department a carefully collected suite which includes every recognizable peaty layer within the Armenta horizon at the place where the composite peat sample was taken. Other woody specimens that may prove interesting include peat and wood from the bone beds of Tequixquiac, as well as wood from an oldish-looking alluvium along Alseseca Creek on the eastern outskirts of the city of Puebla.

GLACIOLOGY AND VOLCANOLOGY ON POPOCATEPETL

Sidney White of the University of Syracuse has completed his second summer on the peak Popocatepetl, where snow lies throughout the year. With the aid of aerophotos and aneroid altimeter he mapped the physiographic features, especially those that may demonstrate glaciation. No evidence of appreciable glaciation on Popocatepetl has been presented up to now.

THE "OCOTE" PLIOCENE MAMMALIAN FAUNA

Through the kindness of Ing. Enrique Díaz Lozano, Professor of Paleontology at the School of Engineering of the National University of Mexico,[6] C. W. Hibbard identified in August 1949 a small collection of fossil teeth as probably *Pliohippus* and rhinoceros. In March 1950 Chester Stock thought that the horses of this collection probably would be a little older than those from Yepómera in Chihuahua,

[5] J. R. Arnold and W. F. Libby as of September 1, 1950.

[6] Actual designation. This school occupies the building erected at the end of the 18th century for the Royal Seminary of Mines. In it are housed important fossil collections.

which he considered high Hemphillian. In April 1950 Arellano collected from this locality several hundred horse teeth, several mastodon molars, two upper and two lower rhino (*Aphelops?*) cheek teeth, and some peccary, canid, sabre-toothed tiger and other unidentified material.

Preliminary identifications would indicate the presence of: a *Neohipparion* close to *phosphorum* Simpson from Florida; a *Nannippus* about the size of *montezuma* (Leidy) from Zacualtipan and another one close to *minor* (Sellards) from Florida, with intermediate sizes; a large *Pliohippus;* and a smaller *Pliohippus*, close to *P. castilli* (Cope) from Zacualtipan. Stock's tentative correlation seems well substantiated by the abundant horse material which will further clarify the suggestion made by Stock and by Lance that the Florida Pliocene horses may be very close to those from central and northern Mexico.

The bone bed is about 2 m. thick, but the bulk of the fossils come from a layer not more than one meter in thickness. It consists of white to light green or yellowish silty sand with coarser detritus disseminated, or in pockets or lenses. The Ocote ranch is in the district of San Miguel Allende, in the east-central part of the state of Guanajuato.

IMPRESSION OF A HORSE AT LA TINAJA, SAN LUIS POTOSI

In April, 1950 Arellano visited this almost legendary locality and found that only the lower half of the front limbs and a vague impression of the hind hoofs still remained. According to local informants,[7] this "fossil" has been known as far back as can be remembered by tradition (which may mean a hundred years or more). It is on a coarse conglomeratic sandstone which forms a veneer a few meters thick on Cretaceous limestone. The age of this sandstone may be Pliocene but could be Pleistocene.

Ing. Mariano Moctezuma, former Director of the School of Engineering of the National University of Mexico, had a plaster of Paris cast made of the impression sometime in the 1920s, and deposited it at the Museum of Paleontology and Mineralogy of that school. The size of the cast is that

[7] Dr. Antonio de la Maza, San Luis Potosi, and the owners of the Hacienda de la Tinaja, as well as other ranchers. This Hacienda is 35 km. NNE from the city of San Luis Potosi.

of a rather small horse; the reproduction of the feet is not sufficiently accurate to determine the existence of side toes, if any existed.

The suggestion that instead of being a fossil this may be a carving of post-Columbian, or even pre-Columbian man has been considered rather improbable because of the isolation of the site, but remains a problem.

NEW BECERRA LOCALITIES

1. In the San Miguel Allende district at Rancho Viejo, glyptodon scutes very similar to those of *Brachyostracon* were taken from a whitish gravelly alluvium.

2. At the City of Celaya the trench dug for the new petroleum pipeline exposed typical Becerra underlying well-developed Barrilaco paedocal. No fossils were found.

3. A few kilometers southwest of the City of Guanajuato, an elephant molar and a horse mandible and skull were collected by John Edwards, temporarily with the U. S. Geological Survey in Mexico. From the nature of the fossils as well as from information supplied by Edwards, the elephant molar and the horse mandible probably were found in the local equivalent of the Becerra; the skull on the other hand may be post 1520.

4. The sewerage excavations in the city of Aguascalientes exposed along Calle de Hornedo a Becerra section with its Barrilaco caliche on top; at the bottom of this calichized material an elephant tooth was found.

5. Close to the town of Tula, Tamaulipas, the excavations for a damsite revealed fossil elephant and horse teeth in a mud-flow sort of alluvium with typical weathering. In the creeks close to town a tusk was found in a gravel lens with appreciable limonitization which stratigraphically should correspond to the bed with elephant-horse at the damsite.

6. Near Texcoco, on the eastern border of the Mexico City Basin, about 40 meters above the present lake, elephant remains are found in an old alluvium.

7. Within Mexico City a number of excavations have been studied to observe the character of the Becerra and adjacent beds, notably the site for the Latino Americana insurance company building, where the excavation is 12 m.

deep. Here maize pollen has been reported from the Becerra strata (Sears, 1950)[8]. Dr. Leonardo Zeevaert, foundations consultant, is investigating the correlation between physical properties and stratigraphical position of these beds, especially with a view to finding weathering surfaces.

THE SEMINARIO PARA ESTUDIOS CENOZOICOS

In order to further scientific investigations of the Cenozoic of Mexico, this research and study unit has been organized. It functions under the Geological Institute of Mexico and its more specific purposes include:

1. Helping qualified scientists to conduct research in any phase of the Mexican Cenozoic. This help may be material, such as transportation, equipment, field expenses, field assistants, etc.; or it may consist merely in supplying information and acting in a liaison capacity between the researcher and other Mexican official bodies or individuals.

2. Organizing projects to be conducted either by members of the Geological Institute, by graduate students of the University of Mexico or of foreign universities.

3. Obtaining funds for the publication of the results of these investigations when they cannot be published promptly in adequate journals.

4. Publicizing the very great need for Cenozoic research, especially on continental deposits which have been relatively neglected. The projects most needed at present seem to be: field mapping of type areas, studies in sedimentation and volcanology, in vertebrate paleontology, in soil geology, and in physiography. Locally invertebrate paleontology and paleobotany (including pollen analysis) and special analytical methods, such as radiocarbon datings, may be of the greatest importance.

The organization of the Seminario para Estudios Cenozoicos has had at its head four permanent counselors. Kirk Bryan, Helmut de Terra, Claude W. Hibbard, and Chester Stock, who have given so much of their personal effort to further these researches in Mexico, consented to act in this capacity. During the preparation of this paper the geological profession suffered the loss of Kirk Bryan, whose worldwide

[8] This discovery seems confirmed by further work in Mexico City of Sears and Kathryn Clisby, associated with L. Zeevaert and Arellano.

renown was the consequence of a profound devotion to international collaboration. While this paper was being edited, the death of Chester Stock, President of the Geological Society of America, came as an incredible shock to those who counted it among their rare privileges to have known him. It is with the deepest appreciation that we record our indebtedness to these two great scientists and teachers.

References

Drescher, A. B., 1939. A new Pliocene badger from Mexico: Southern California Acad. Sci. Bull., vol. 38, pp. 57-62.

Furlong, E. L., 1941. A new Pliocene antelope from Mexico: Carnegie Inst. Washington Pub. 530.

Lance, J. F., 1950. Paleontologia y estratigrafía del Plioceno de Yepómera, Chihuahua, part 1, Equidos, excepto *Neohipparion*: Inst. geol. Mexico Bol. 54.

Miller, L. H., 1944. A Pliocene flamingo from Mexico: Wilson Bull., vol. 56, pp. 77-82.

Sears, P. B., 1950. Pollen analysis in Old and New Mexico: Geol. Soc. America Bull., vol. 61, p. 1171.

Stock, Chester, 1948. Restos de tejón (Taxidea) Pliocénico del occidente de Chihuahua: Soc. geol. mexicana Bol., vol. 13, pp. 69-76.

———. Paleontologia y estratigrafía del Plioceno de Yepómera, Chihuahua, part 2, *Neohipparion*. (Submitted for publication to the Geological Institute of Mexico.)

Wilson, R. W., 1937a. Pliocene rodents of western North America: Carnegie Inst. Washington Pub. 487, pp. 21-73.

———, 1937b. A new genus of lagomorph from the Pliocene of Mexico: Southern California Acad. Sci. Bull., vol. 36, pp. 98-104.

Stratigrapher

Geological Institute of Mexico

Mexico, D.F., Mexico

ESSAY REVIEW

Geography in the Twentieth Century; by GRIFFITH TAYLOR, Editor, with twenty contributing authors. Pp. x, 680; 56 figs. New York and London, 1951 (Philosophical Library, and Methuen & Co., Ltd., $8.75).—Non-geographers (and some geographers) who have been ignorant of or confused about the nature of modern geographical science will find that a reading of *Geography in the Twentieth Century* will change and clarify their concepts about the field of geography today. Perhaps this book illustrates the same theme upon which Richard Hartshorne expounds in his *Nature of Geography.* The latter, however, is more concerned with a systematic exposition of the philosophical content of modern geography and of certain aspects of cartographic techniques. By contrast, the present volume comprises the direct contribution of numerous different authors, in chapters grouped into three parts.

Part I presents a historical account of the inter-related and mutually influenced development of geographical sciences in different parts of the Western World. The distinctive contributions of leading geographers of Europe and America in the ramifying process of evolution of the geographical sciences are here described. In this list of eminent men, the German Alexander von Humboldt is given his place as "the father of modern geography." Developing a type of geography suggesting that the Earth itself plays a part in determining the type of life which evolves in a particular area, Humboldt broke away from the more strictly teleological slant of the earlier sciences of the Middle Ages.

German geographers greatly influenced the 19th Century development of American geography, particularly in the persons of Karl Ritter, Humboldt, and Friedrich Ratzel. However, the philosophic current also flowed at times in the other direction. Equal to the greatest of the 19th Century geographers of Europe, the American William Morris Davis had a strong influence in Germany in his emphasis on physiography.

Environmentalism in the development of man is as old a question as Hippocrates and Strabo. It derived from the attempt to understand the variation in the character of human types. Buckle in England, Demolins in France, and Semple in the United States were prominent exponents of determinism, an extreme form of environmentalism, in the 19th and early 20th Centuries. However, the deterministic thesis is one that geographers have largely abandoned. It has been counter-balanced increasingly by the view of the pattern of human activity on the earth's surface as the result of the initiative and mobility of man operating within a frame of natural forces.

In discussing "environment as a factor," Part II has separate chapters taking up the progress of geomorphologic presentation, the

significance and effects of climate and soils, the nature and study of "zonal" and regional geography, and such differing types of field work as Antarctic exploration and British land use surveys.

The geomorphologist perhaps is the keystone of the bridge between geology and geography. Woolridge notes that, because the emphasis has been on geomorphology as the complement of stratigraphical geology, many geographers have been led to doubt its relevance in their proper field. However, he points out that the methods and conclusions of geomorphology are necessary alike to the geologist in reconstructing the history of the planet, and to the geographer concerned with what has been its "areal differentiation."

The boundary between the fields of meteorology and geography is poorly defined, according to F. K. Hare, and the proponents of one have tended to shun the field of the other. World War II disrupted this isolation and has served to draw the skills of one field to those of the other. The developments of modern meteorology from radar storm detection to rain-making, therefore, have been of increasing interest to climatologists.

D. F. Putnam points out that the study of soil character and classification is a special contribution of Russian soil scientists and geographers. Their influence has led to the important position of soil study and classification in the various agricultural departments of this country, as well as in the academic field. As an essential element in the conservation picture, soils have been dramatized in several recent books dealing with the world's food problems. The most recent version of the soil classification used by the U. S. Soil Survey has been published in a symposium by leading American soil scientists in the February 1949 issue of Soil Science.

The latter half of Part II of this volume presents the special problems of the "difficult" parts of the earth,—the pioneer fringe, the cold lands, the hot lands, the dry lands, and the over-wet lands. Isaiah Bowman in one of the last of his numerous contributions to geographical literature writes of the studies undertaken on modern frontier areas of Canada, Australia, Brazil, and Africa. He points out that the modern pioneer is in a markedly different situation from earlier pioneers. He "is tied to world conditions and events which he does not control. He is no longer a breed, as it were, but any one of us trying to make a living under difficult conditions with risk offset by hope and promise." This might apply to both white settlers and the indigenous peoples in the Asiatic tropics whose problems and prospects are admirably discussed in Karl Pelzer's chapter on Geography and the Tropics.

Inevitably, discussions of the problems of land use, to have any value, must derive from field studies, directly as in the case of field surveys, or indirectly as in the case of census returns; or they must lead to such studies. Because the population of the

British Isles has so far outrun the food support from their own lands as to imperil their existence in critical times of blockade, the problems of land use have been the subject of an intense field study on a national scale in Great Britain. The results form the basis for rational planning of land use for the nation and for individual localities. L. Dudley Stamp draws attention to the Commission recently appointed by the International Geographical Union for a World Land Use Survey on a scale of 1:1 million, indicating the increasing concern with land use the world over.

Part III follows aptly with a discussion of field techniques and laboratory methods in the practical applications of geography. Equipment used in traverse and contour work, the most suitable types of maps for field sheets, techniques of recording and sketching, block diagrams and isopleths, projections and aerial photographs all receive brief mention.

Part III in its comprehensive orbit of "Special Fields" lays special emphasis on human geography: political, racial, sociological and urban. The changing concepts owing to the development of air navigation are described by the late Ellsworth Huntington. Director J. K. Wright of the American Geographical Society delineates the history and functions of geographical societies and their notable contributions. A chapter also is devoted to geography in the U. S. Government service.

Among the six chapters from his pen, Editor Taylor includes one on the controversial subject of geopolitics and what he calls "geopacifics." Geopolitics he finds, was wrong primarily as to the purpose underlying its development. It centered around a political theory of geography directed toward explaining the inevitability and the justification of the expansion of the totalitarian nations, particularly Germany and Japan. Geopacifics, which Taylor admits is a hybrid coined as the antithesis of geopolitics, is defined as "an attempt to base the teachings of freedom and humanity upon real geographical deductions." While it may be antithetical to geopolitics, it could hardly be regarded as a school of thought among modern geographers. Its objective would be that of any scholarly study directed toward the betterment of knowledge and understanding of the rest of the world.

The final chapter is unusual in that a glossary which would normally appear in an appendix is tied in as an integral part of the text material.

The reader searching for an account of the growth, fields, techniques, aims and trends of geography in the Western world in the 19th and 20th Centuries finds much of his information gathered here in one volume. The different articles on the whole are quite readable, and the editor and authors are to be congratulated.

HEROLD J. WIENS

REVIEWS

Geography of the Pacific; by OTIS W. FREEMAN, Editor, with thirteen Pacific Area specialists. Pp. xii, 573; 154 figs. New York and London, 1951 (John Wiley & Sons, Inc., and Chapman & Hall, Ltd., $10.00 (school rate, $8.00)).—The Pacific lands do not have a natural geographical coherence that would make logical the inclusion of all of them in one textbook. The problems of the rimland continental areas are too vast to be compressed advantageously into such a volume. This is particularly true when the plan intends the presentation of all aspects of geography, physical, historical, cultural, and economic.

Nevertheless, the strategical aspect of an indivisible and interrelated Pacific area, accentuated by World War II, has long worried geographers teaching about Pacific lands and peoples. Hence, the present compilation, *Geography of the Pacific,* with all the defects of such compendiums, furnishes a useful tool in the study of Pacific geography.

The criteria used for inclusion or exclusion of Pacific lands to be discussed appear to be very vague. The Pacific coastlands of the Americas and of Asia are omitted because they have been "adequately treated" in other books. For the same reason, Japan is not treated. However Australia, for which more adequate treatment than here given can certainly be found elsewhere, is included for some reason not disclosed. Perhaps a justification for its inclusion might be its evolution historically as a part of the Pacific lands developed as a result of European discovery and initiative. Former appendages of Japan such as the Kuriles and the Ryukyus are given a special section, whereas Sakhalin, Formosa, and Hainan Islands, far more important, are not discussed.

There is some lack of balance in treatment. For instance, four short paragraphs tell about mining and industrial development in Indonesia; whereas about twice as much space is devoted to listing various fauna such as squirrels, lemurs, hares, bats, flying foxes, rats and mice, not to mention others like pigeons, cockatoos, chichaks, leeches, scorpions, and orangutans. There also is no uniformity of practice in illustration. Thus, climatic graphs of seasonal precipitation and temperature changes are given for places in the Caroline, Philippine, and Hawaiian Islands, but they are not found where they are more significant, as in Australia and New Zealand.

Generally, there is a brief delineation for each area of its history, geology and topography, climate, soils, vegetation, fauna, peoples, cultures, economic development, and problems. There are so many places involved that often this information must be very succinctly told, so that the total aspect tends to be encyclopedic in character. It will be a difficult textbook for students that are inclined to mem-

orize information, because the number of islands described, and the wealth of detail buries the generalizations from sight. Moreover, few of the maps are adequate.

One learns interesting facts about each place, however, since, presumably, each of the thirteen authors has traveled in the areas he describes. Thus, we read that Truk is pronounced Chuk; that the fruit bat is caught in nets for food in the Marianas; that, unlike the population of most parts of the world, the absolute number of people in the Marquesas has declined drastically—from an estimated 50,000 in 1842 to only about 2,400 today; that there are several fairly large glaciers in the mountains of New Zealand, remnants of vast Pleistocene ice-streams; that Pribilof fur seal bulls weigh an average of 400-500 pounds each, contrasted with the average of only 80 pounds for females.

In short, this volume collects in one book more than a dozen articles describing the geography of most but not all of the important island areas (including a continental one) of the Pacific. The first three chapters attempt to provide an integrating framework of the geography, history, and culture of the whole Pacific region, while the last chapter tries to draw in all loose strings concerning trade and transportation, and the strategic aspects of Pacific situation. What it has lost in structural coherence, the book has gained in the greater intimacy of knowledge of the multiple authority writing the volume. There is a need for a book on Pacific geography. Perhaps this volume fills the need about as successfully as can be expected.

HEROLD J. WIENS

Hematin Compounds and Bile Pigments, Their Constitution, Metabolism and Function; by R. LEMBERG and J. W. LEGGE. $15.00).—This authoritative monograph summarizes to date the researches in this vast and important field of investigation and as such becomes a worthy companion to the monumental monograph of Fischer, Orth and Stern. Whereas the earlier monograph was directed primarily to the organic chemist, the present work places its major emphasis on the physiological and biochemical aspects of the pyrrole pigments. Nonetheless the organic chemist and, perhaps even more, the physical chemist working in biological fields will find it to be valuable and stimulating reading.

Particularly commendable is the organization of the book which, after a short introduction, proceeds with a chapter devoted to the various physico-chemical methods of investigation employed, written in collaboration with J. P. Callaghan. The two ensuing chapters are devoted to the problems of structure and isomerism of the porphyrins and bile pigments and certain related compounds, to-

gether with their occurrence in nature and methods of isolation and estimation. From this the next chapter develops the subject of the metallo-complexes or hematin compounds and then leads on to hemoglobin itself, from which the book proceeds to chapters on the hematin enzymes—the cytochromes, catalase and the peroxidases. Then follow chapters on the mechanism of bile pigment formation and hemoglobin catabolism, after which the authors take up the problem of biosynthesis of porphyrins. This last named chapter is of particular interest in view of the presentation of a new theory of porphyrinogenesis which is made the more attractive by a correlated mathematical treatment which neatly accounts for the ratio of type I to type III porphyrins in nature.

In their treatment of the various topics, the authors present the pertinent evidence, critically weigh the conclusions of the original investigators and not infrequently propose new interpretations and suggestions for further work. As a text for the student and workers in other fields who wish to acquire some knowledge of the subject, this treatment makes possible the acquisition of a background that could otherwise be obtained only by a long and intensive survey of the literature. The 3182 indexed references together with numerous footnotes citing more recent contributions make the book an invaluable asset to the library of the worker in the field. The book is singularly free of typographical errors, this reader having found but three, which were present in figures accompanying the text.

ALFRED H. FRYE

The Nomogram; by H. J. Allcock and J. R. Jones. Fourth edition, revised by J. G. Michel. Pp. x, 238. New York and London, 1950 (Pitman Publishing Corporation, $3.75).—This textbook presents a course of instruction on the theory and practice of nomography. The approach is almost entirely through determinants; the alignment chart is emphasized, other types of nomograms being treated subordinately. The subject of nomograms that relate four or more variables is developed with clarity and finesse. The last chapter, new in this edition of the book, shows all too briefly the interesting relations between alignment and intersection nomograms, relying especially upon the duality of Cartesian coordinates and D'Ocagne's parallel-line coordinates. Appendix I contains a summary of standard equations, together with their respective alignment charts and determinants. Appendix II includes a few rules for handling determinants that perhaps might better have been included in the text. The book is liberally sprinkled with references from one part to another; where the reference is to an equation more than a few pages away, it would aid the student to have the page as well as the equation number. The

treatment as a whole is on a moderate level, well adapted for the serious scientist or engineer, but not for the technician.

HORACE WINCHELL

Stratigraphy and Structure of the Castleton Area, Vermont; by PHILLIP FOWLER, Vermont Geological Survey Bulletin 2. Pp. 88; 8 figs., 4 (2) plates in pocket. Montpelier, 1950 (Vermont Development Commission). The Castleton 15-minute quadrangle in Vermont covers most of the north end of the Taconic mountain range, whose geology has long been a bone of bitter contention. The "Taconic controversy" has passed through several distinct phases, the latest of which concerns the hypothesis that the slates and phyllites of the Taconic range are a great klippe, thrust to its present position from roots miles to the east.

The State of Vermont has just published a report on this quadrangle, which presents the results of detailed mapping of a critical part of the area and brings together other recent work on the problem. Stratigraphy and structure are well summarized, and a colorful geologic map presented (the colors do not conform to the standard color scheme for geologic systems, perhaps because very few systems are represented). Though the author rejects most of the stratigraphy and structure on which Keith based his idea of a Taconic overthrust, he concludes, in agreement with most recent workers, that the thrust exists. The vexed question of the location of the root zone is discussed, though admittedly it cannot be answered from the Castleton quadrangle. The geologic reasoning seems excellent throughout, and the style, in contrast to many areal reports, is lucid and vigorous.

The present report is the second in a new series of Bulletins of the Vermont Geological Survey, to be devoted mainly to quadrangle reports (the first, by Jarvis B. Hadley, covered the Vermont portion of the Mt. Cube 15-minute quadrangle, along the Connecticut River). Vermont and its state geologist are to be congratulated on the high calibre of the reports so far published.

JOHN RODGERS

PUBLICATIONS RECENTLY RECEIVED

The Transmission of Nerve Impulses at Neuroeffector Junctions and Peripheral Synapses; by Arturo Rosenblueth. Cambridge, Mass. and New York, 1950 (Technology Press of Massachusetts Institute of Technology and John Wiley & Sons, Inc., $6.00).

Electromagnetic Waves and Radiating Systems; by E. C. Jordan. New York, 1950 (Prentice-Hall, Inc., $7.75).

Ultrahigh Frequency Engineering; by T. L. Martin, Jr. New York, 1950 (Prentice-Hall, Inc., $6.00).

Basic Electrical Measurements; by M. B. Stout. New York, 1950 (Prentice-Hall, Inc., $5.75).

Chemical Thermodynamics; by I. M. Klotz. New York, 1950 (Prentice-Hall, Inc., $6.00).

Colloidal Dispersions; by E. K. Fischer. New York, 1950 (John Wiley & Sons, Inc., $7.50).

A Laboratory Manual of Elementary Chemical Analysis; by T. H. Whitehead. Boston, 1950 (Ginn and Company, $1.25).

Genes, Plants and People; by C. D. Darlington and K. Mather. Philadelphia, 1950 (The Blakiston Company, $4.00).

Groundwater in the Peoria Region; by Leland Horberg, Max Suter, and T. E. Larson. Illinois State Geological Survey Bulletin 75. Urbana, 1950.

Fundamentals of Acoustics; by L. E. Kinsler and A. R. Frey. New York, 1950 (John Wiley & Sons, Inc., $6.00).

Norddeutschland und angrenzende Gebiete im Eiszeitalter; by Paul Woldstedt. Stuttgart, 1950 (K. F. Koehler Verlag, DM 37.—).

Introductory Nuclear Physics; by David Halliday. New York, 1950 (John Wiley & Sons, Inc., $6.50).

Deciduous Forests of Eastern North America; by E. Lucy Braun. Philadelphia, 1950 (The Blakiston Company, $10.00).

Space-Time Structure; by Erwin Schrödinger. London and New York, 1950 (Cambridge University Press, $2.75).

Advances in Radiochemistry; by E. Broda. Cambridge Monographs on Physics. London and New York, 1950 (Cambridge University Press, $2.75).

Negative Ions; by H. S. W. Massey. Cambridge Monographs on Physics. London and New York, 1950 (Cambridge University Press, $2.50).

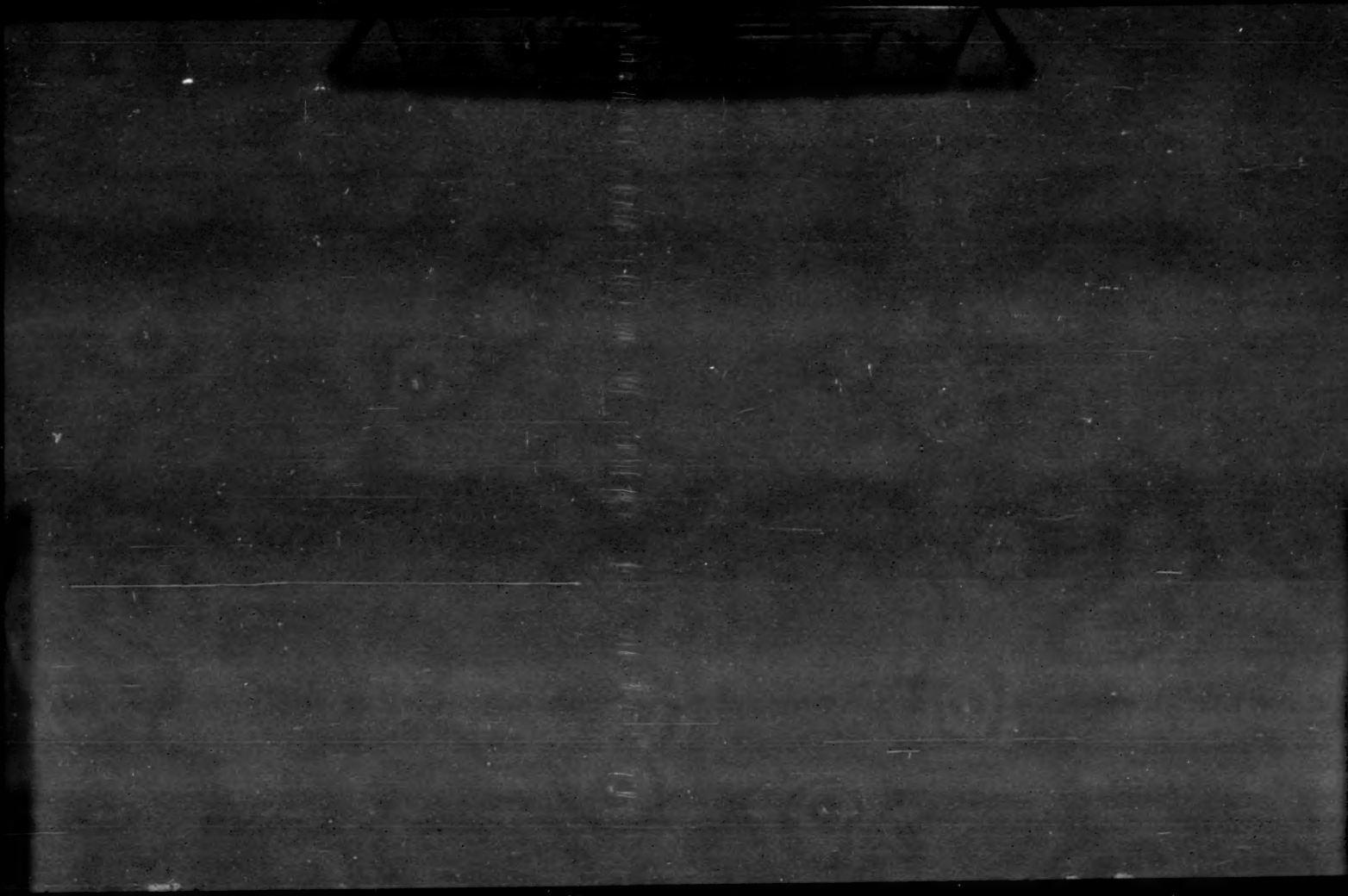
General Chemistry, 3d ed.; by L. E. Young and C. W. Porter. New York, 1950 (Prentice-Hall, Inc., $4.25).

The Nomogram, 4th ed.; by J. H. Allcock and J. R. Jones. New York, 1950 (Pitman Publishing Corporation, $3.75).

Classical Mechanics; by H. C. Corben and Philip Stehle. New York, 1950 (John Wiley & Sons, Inc., $6.50).

Papers of Peabody Museum of American Archaeology and Ethnology, Harvard University, as follows: Vol. 17, No. 3, Flint Quarries—The Sources of Tools and, at the Same Time, the Factories of the American Indian; by Kirk Bryan, $2.00. Vol. 32, No. 2, Masks as Agents of Social Control in Northeast Liberia; by G. W. Harley, $3.25. Vol. 40, No. 2, Some Sex Beliefs and Practices in a Navaho Community; by F. L. Bailey, $3.00. Cambridge, Massachusetts, 1950.

U. S. Geological Survey Surface Water Supply Papers, as follows: 1068, Wells and Water Levels in Principal Ground-Water Basins in Santa Barbara County, California; by G. A. La Rocque, Jr. et al. 1072, Water Levels and Artesian Pressure in Observation Wells in the United States in 1946, Part 2. Southeastern States, $.75. 1081, Surface Water Supply of the United States, 1947, Part 1. North Atlantic Slope Basins, $1.75. 1085, Part 5. Hudson Bay and Upper Mississippi River Basin, $1.00. 1093, Part 13. Snake River Basin, $.60. 1114, Surface Water Supply of the United States, 1948, Part 4, St. Lawrence River Basin, $.65. 1117, Part 7, Lower Mississippi River Basin, $1.00. 1119, Part 9, Colorado River Basin, $1.00. 1120, Part 10, The Great Basin, $.50. 1121, Part 11, Pacific Slope Basins in California, $1.25. Washington, 1950.



Vol. 249 No. 8, 1951

CONTENTS

A Sedimentary Study of Dust Storms in the Vicinity of Lubbock, Texas
G. Frederick Ware and William H. Cox 553

Abrasion of Nine Minerals of Sand Size in Ball Mills
Harold L. Alling 569

The Use of the Terms Pitch and Plunge
R. H. Clark and D. B. McIntyre 591

A Clymenoid Ammonoid from New Mexico
A. K. Miller and Charles Collinson 600

Research on the Continental Neogene of Mexico
A. F. V. Arellano 604

ESSAY REVIEW

Geography in the Twentieth Century; by Griffith Taylor...*Harold J. Wiens* 627

REVIEWS

Geography of the Pacific; by Otis W. Freeman, Editor ....*Harold J. Wiens* 630

Hematin Compounds and Bile Pigments, Their Constitution, Metabolism and Functions; by R. Lemberg and J. W. Legge .....*Alfred H. Frye* 631

The Nomogram; by H. J. Allcock and J. R. Jones .....*Horace Winchell* 632

Stratigraphy and Structure of the Castleton Area, Vermont; by Philip Fowler .....*John Rodgers* 633

Publications Recently Received 636

Payne & Lane, *Printers* — New Haven, Conn.